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Dhondt et al.

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(54) **SYSTEM AND METHOD FOR VEHICLE BUILD VERIFICATION**

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G05B 15/02 (2006.01)

(52) **U.S. Cl.**
CPC **G05B 15/02** (2013.01)

(58) **Field of Classification Search**
USPC 700/110
See application file for complete search history.

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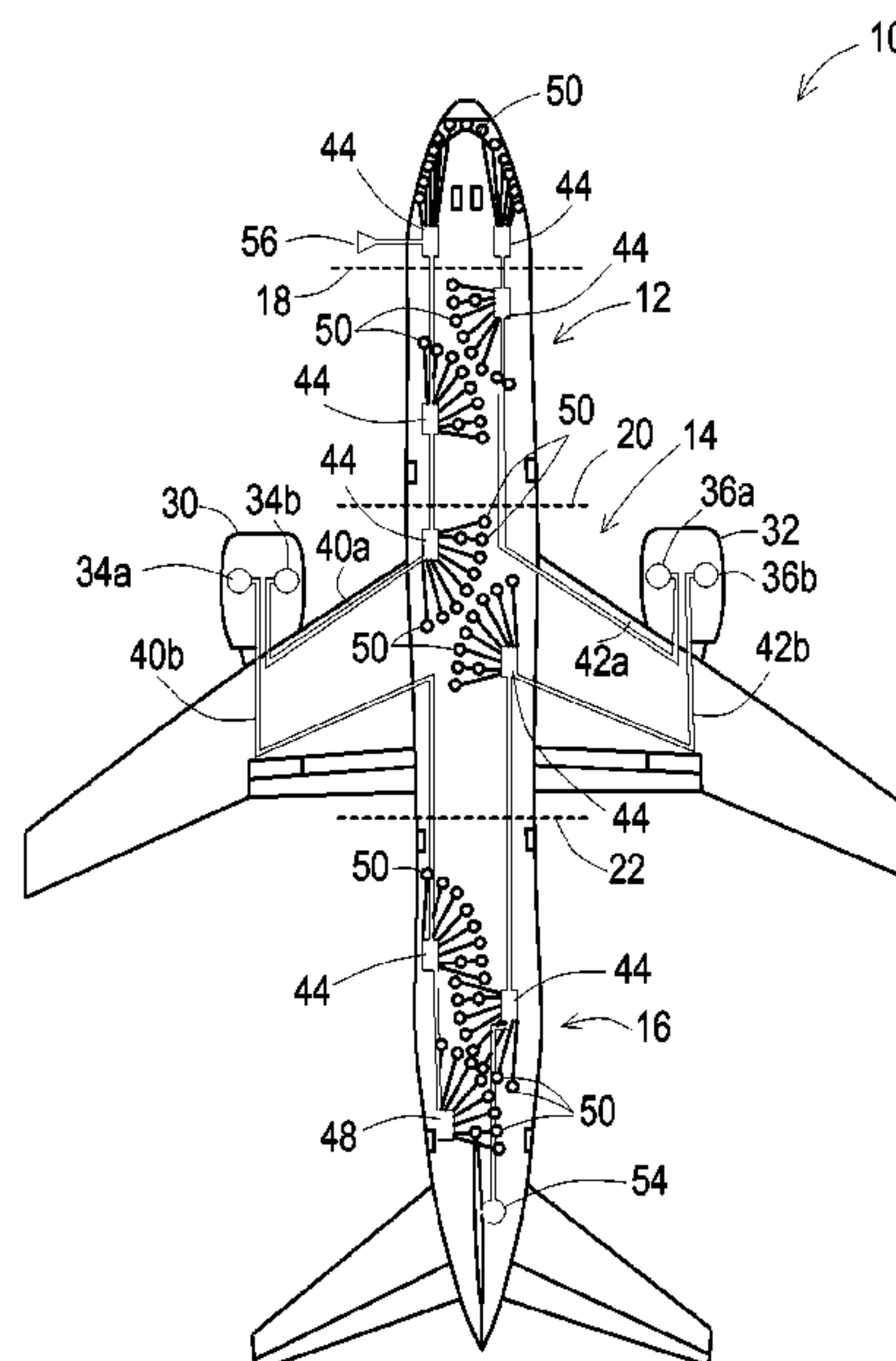
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Primary Examiner — Kidest Bahta

(57) **ABSTRACT**

A system and method for performing build verification of equipment systems after being installed in a partially constructed vehicle portion. After installing one or more of prerequisite equipment systems during a current build stage of a vehicle build plan, the installed equipment systems are tested during the current build stage to determine whether the installed equipment systems are electrically connected correctly.

45 Claims, 33 Drawing Sheets



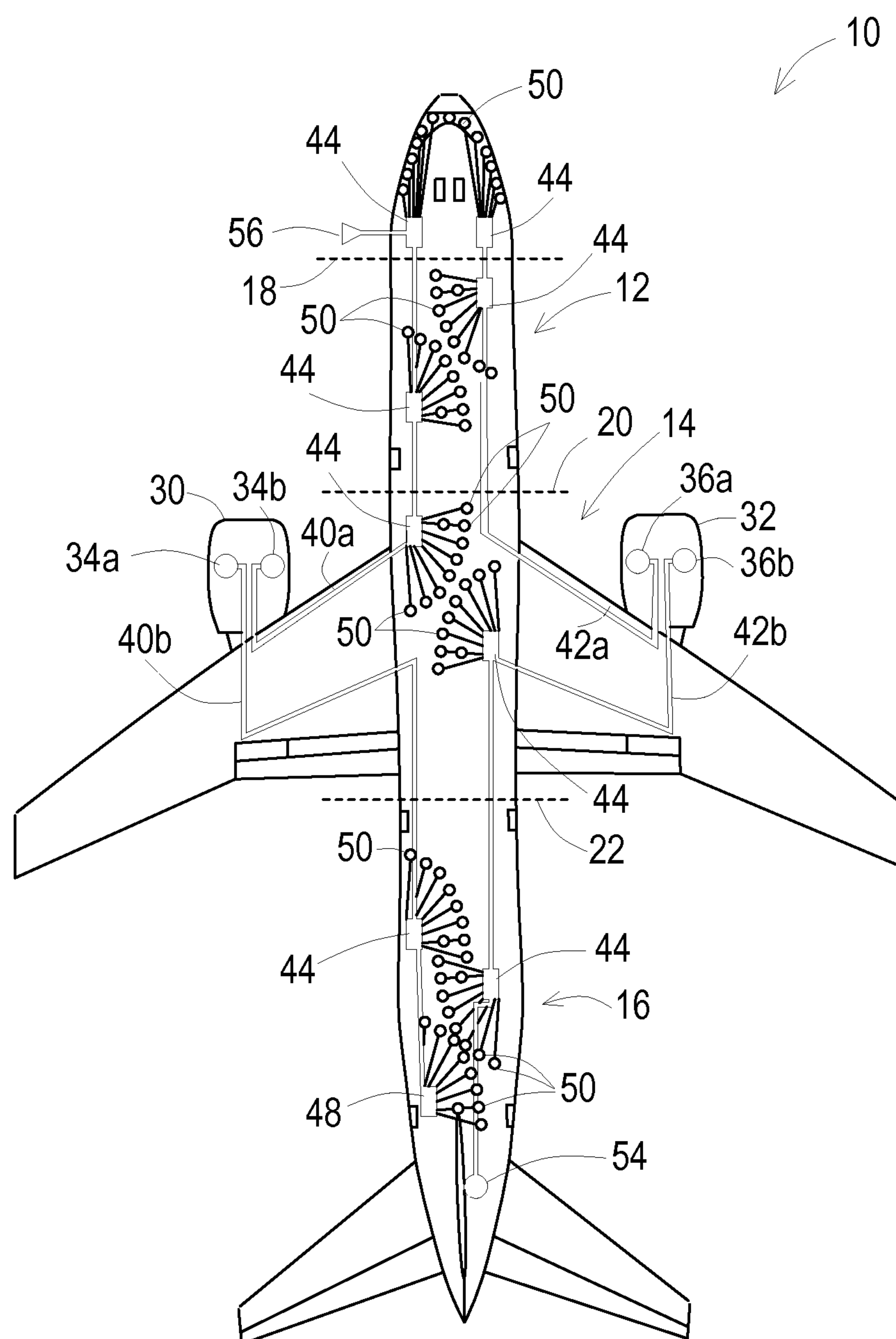


FIG. 1

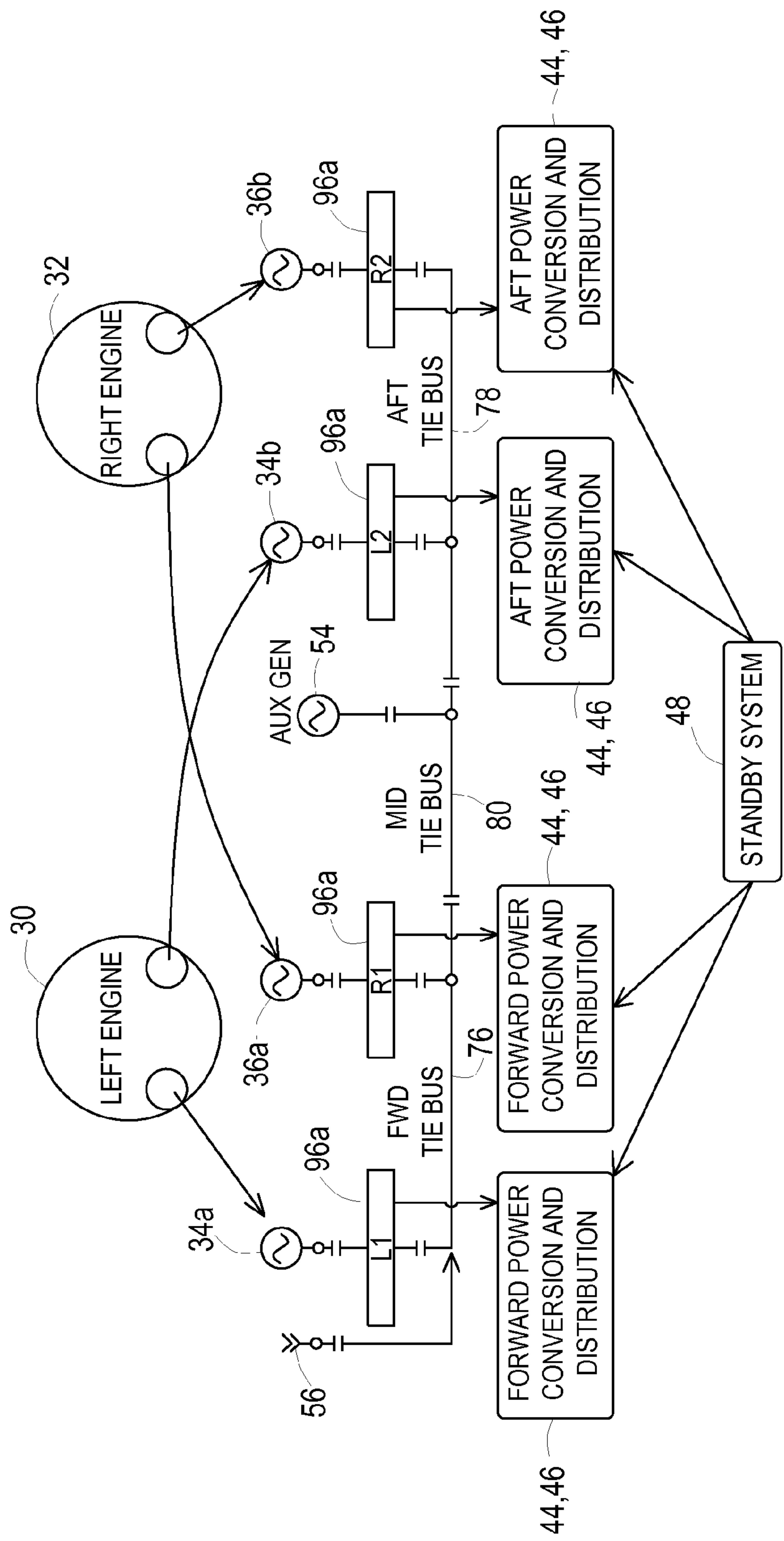


FIG. 2

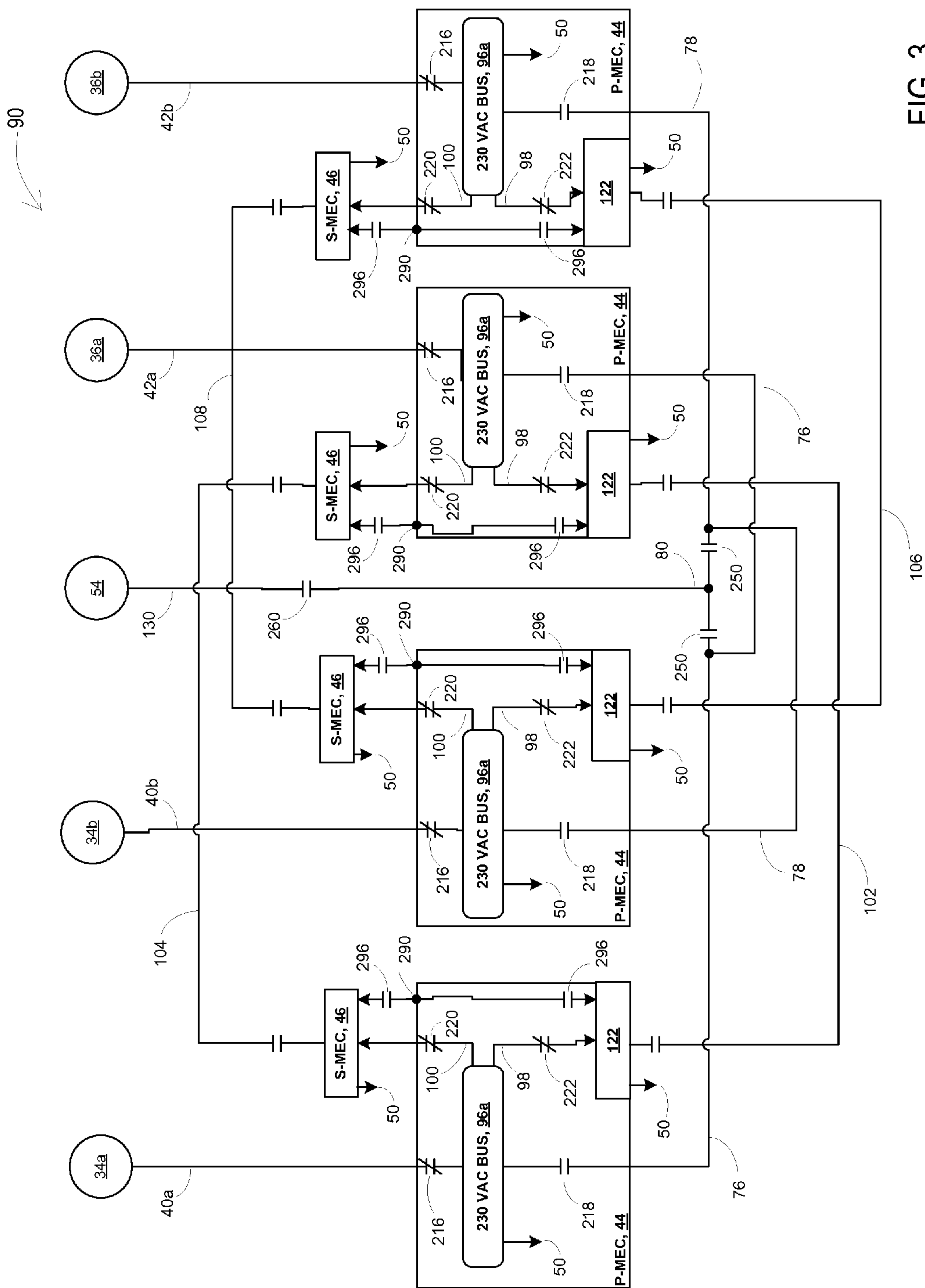


FIG. 3

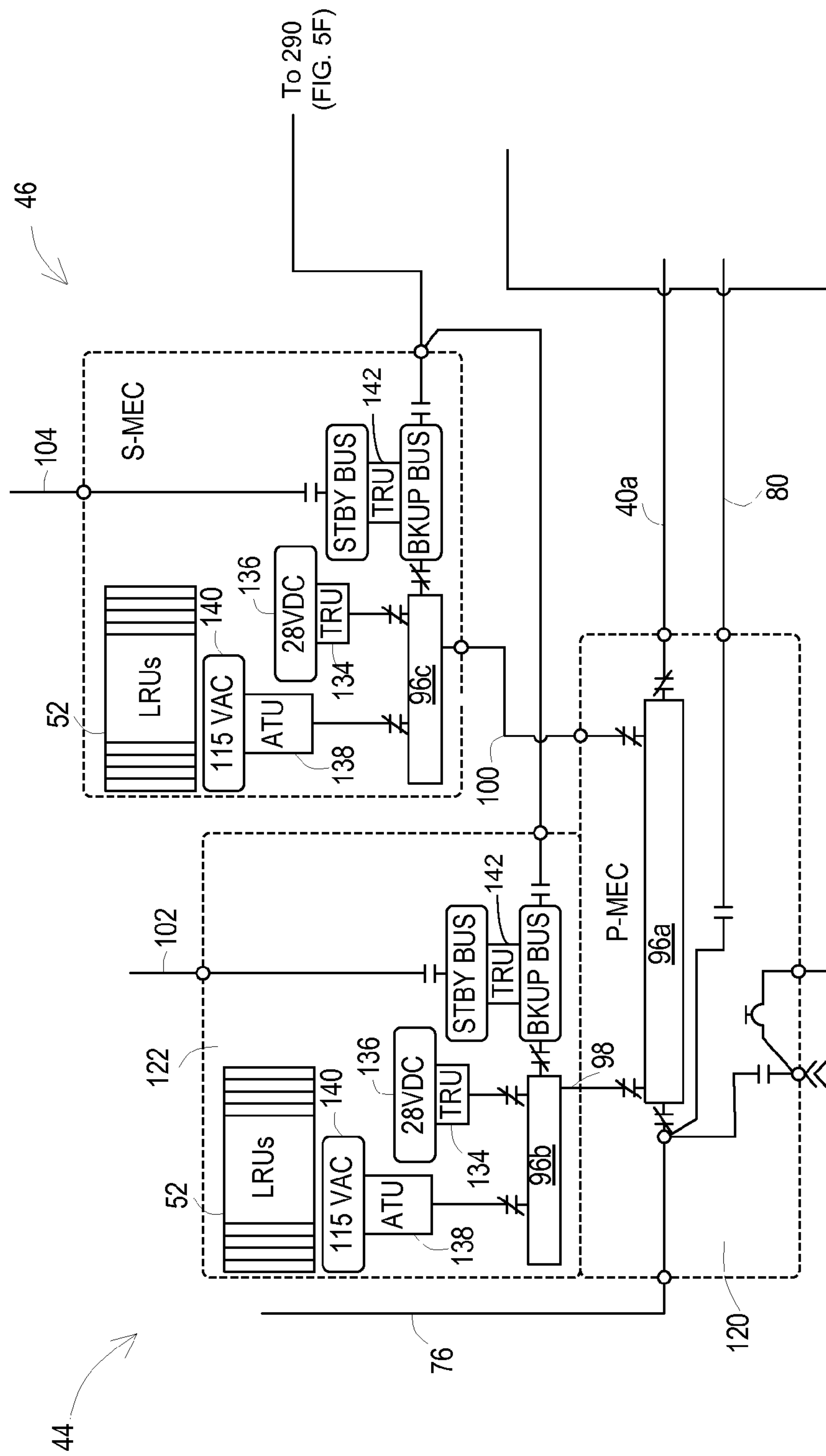
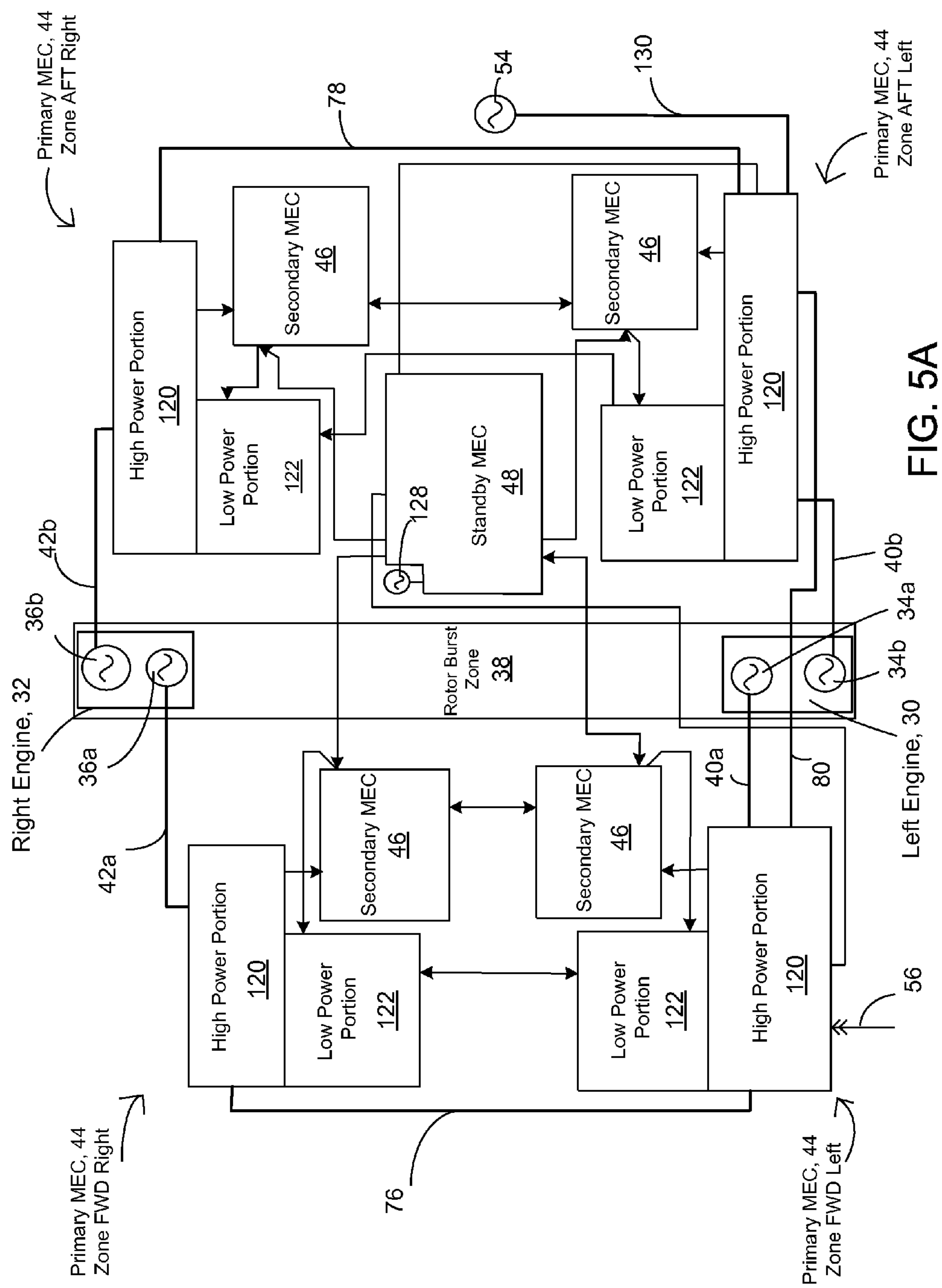


FIG. 4



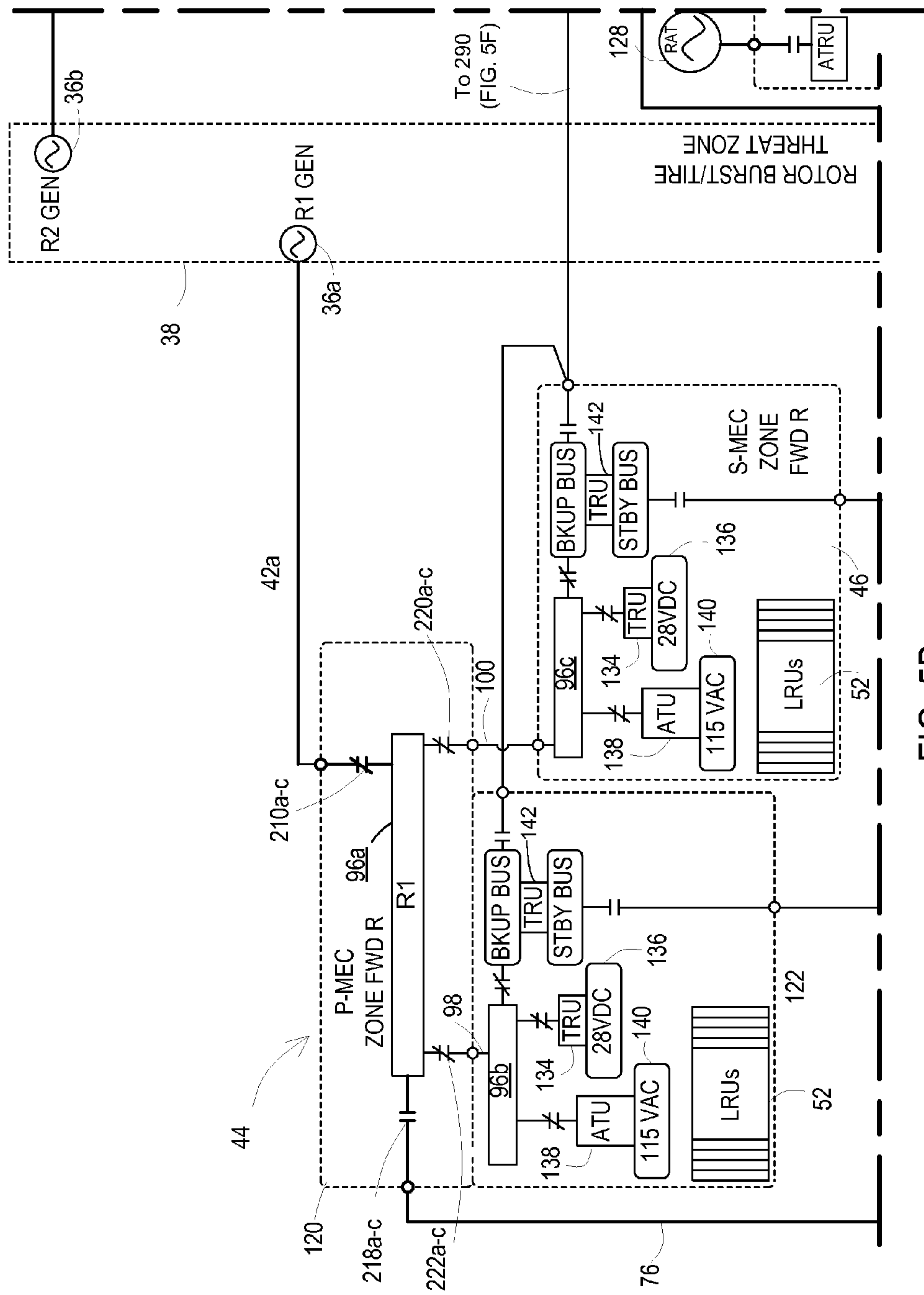


FIG. 5B

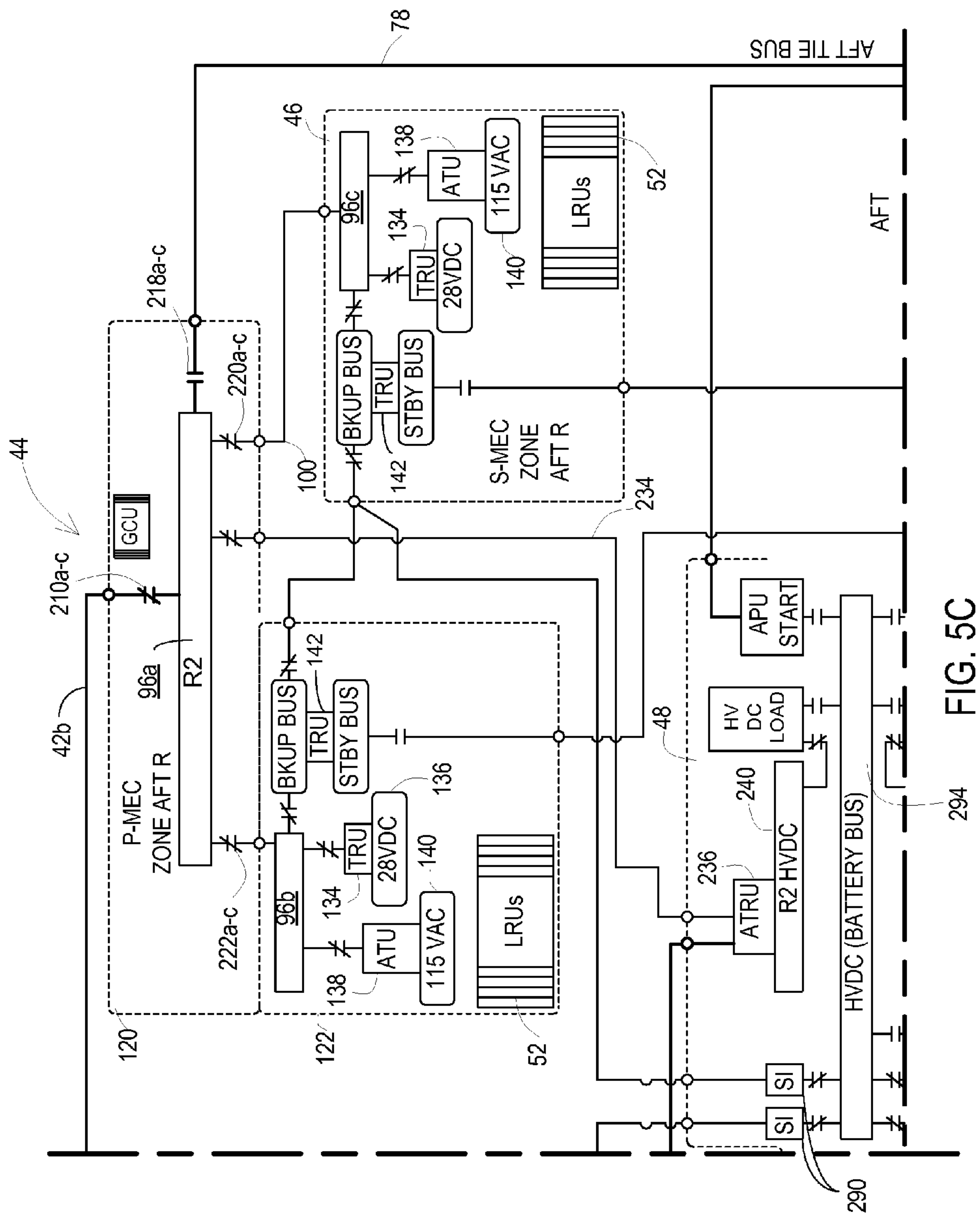


FIG. 5C

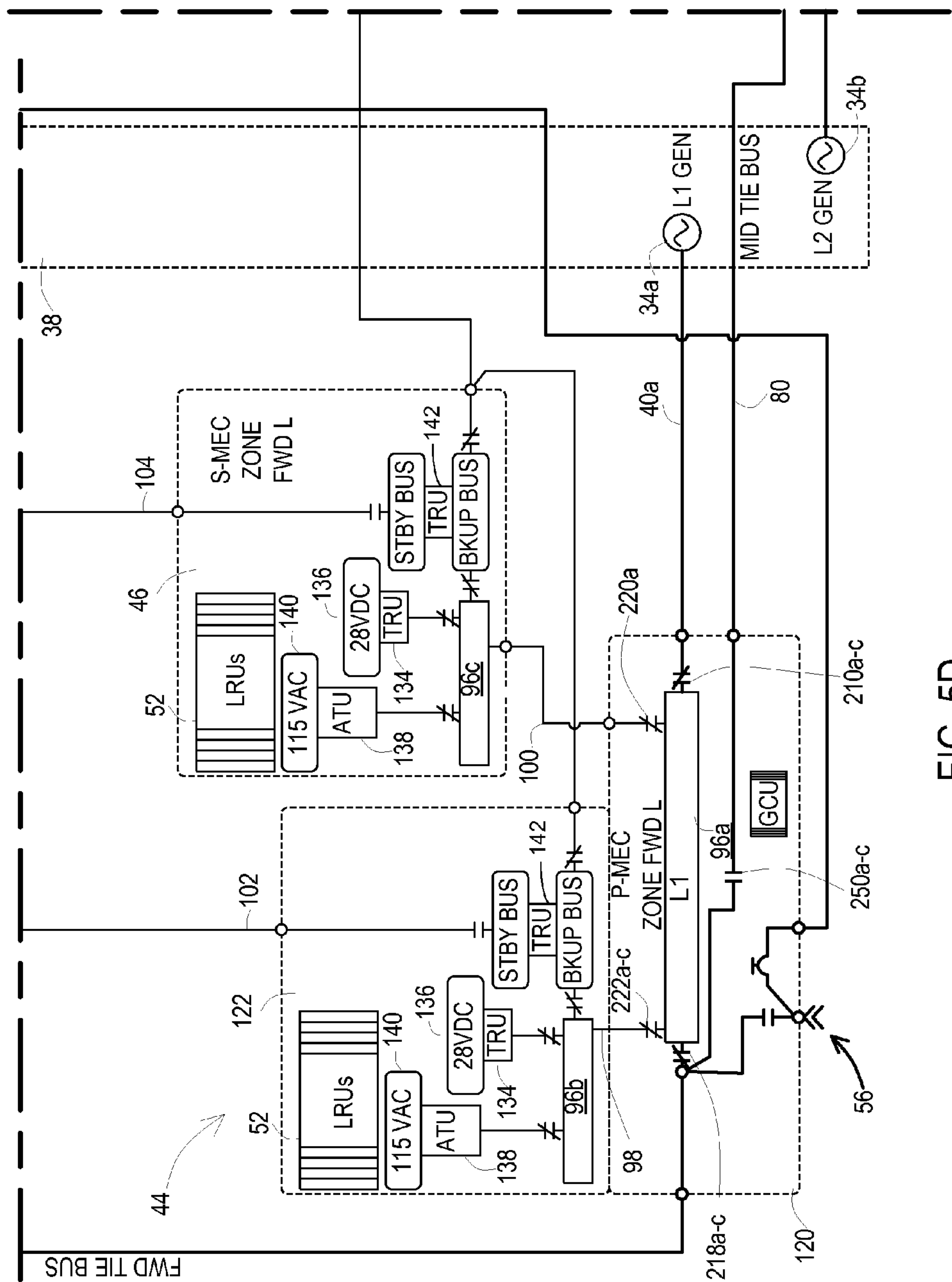


FIG. 5D

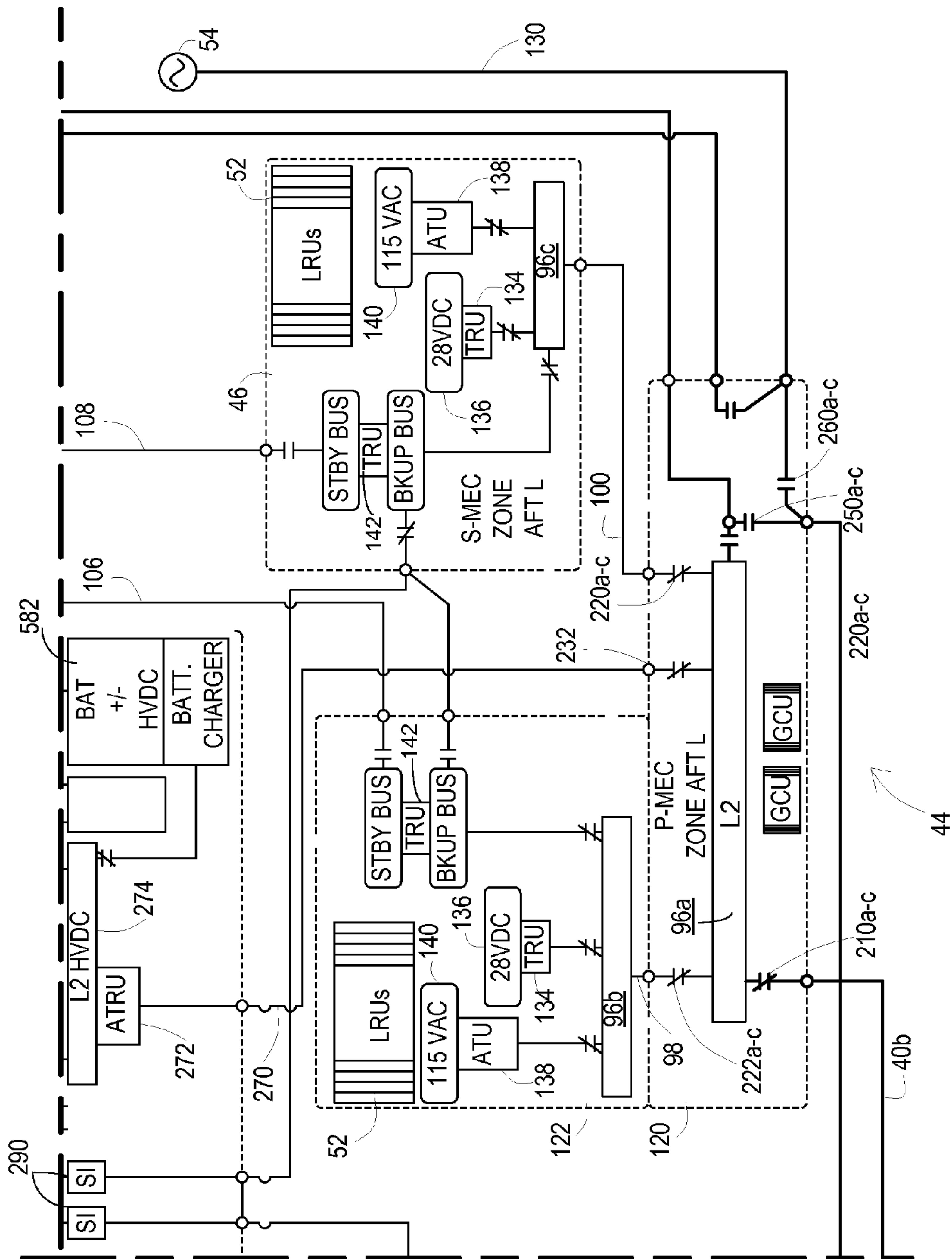


FIG. 5E

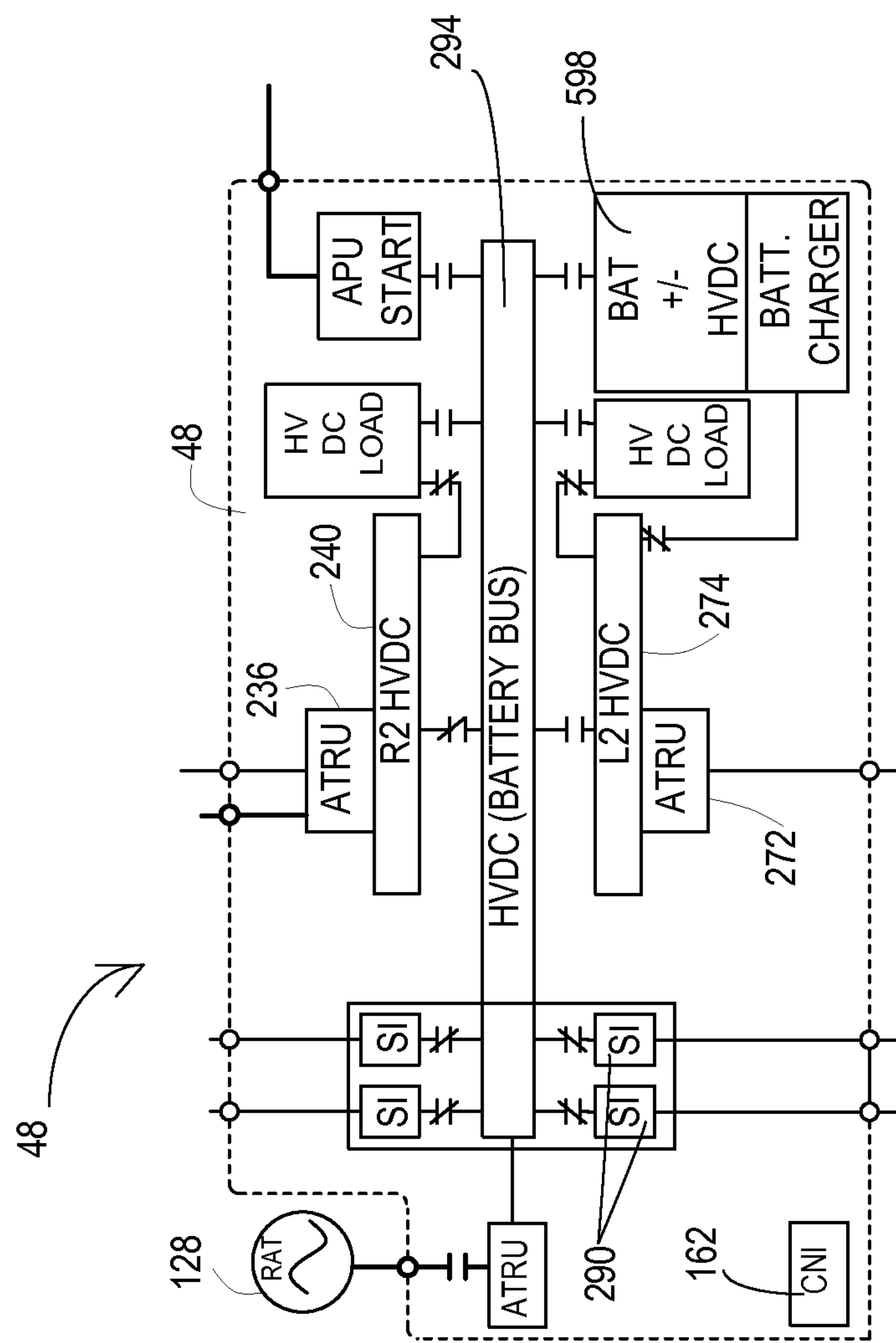


FIG. 5F

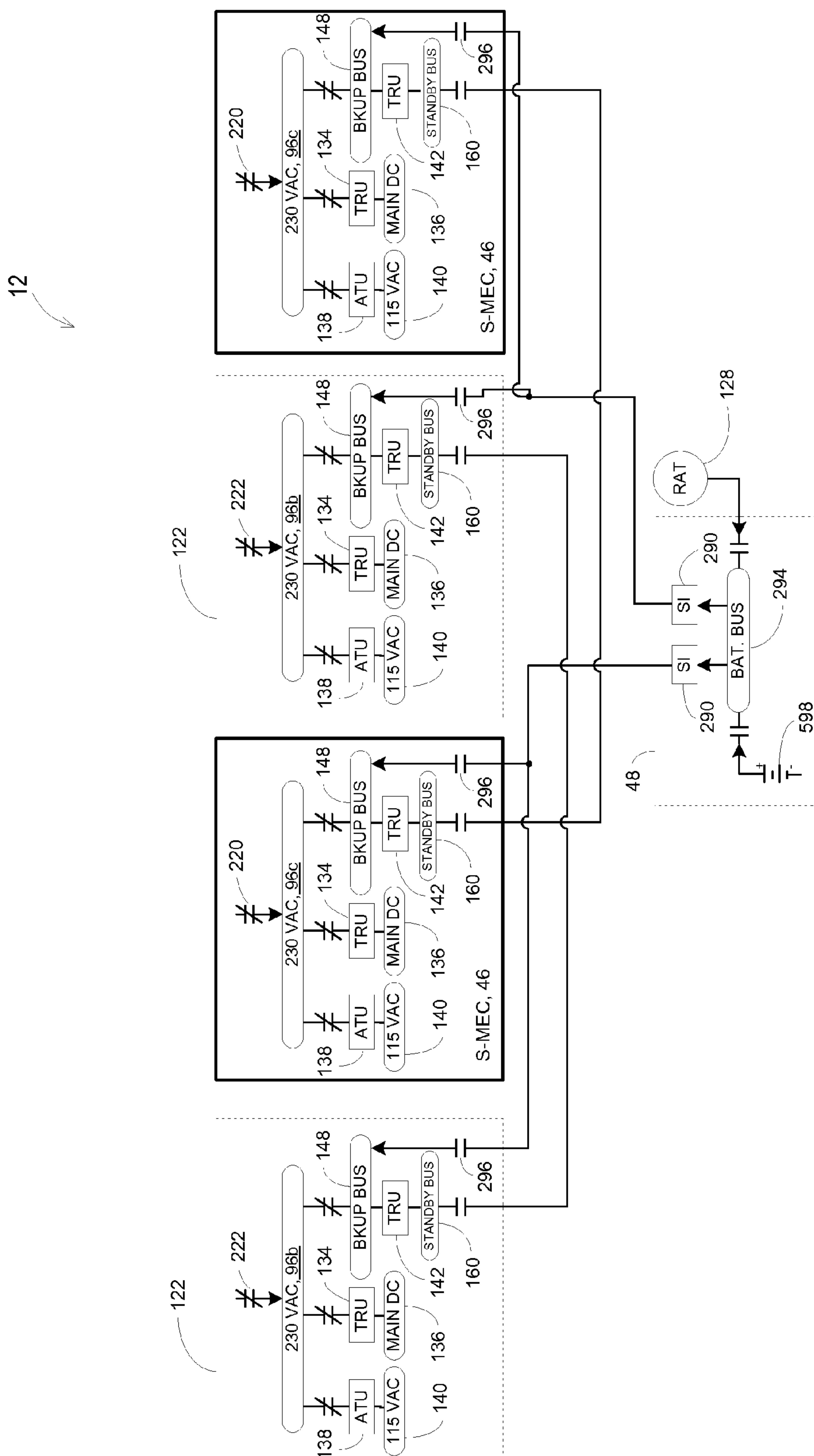


FIG. 6

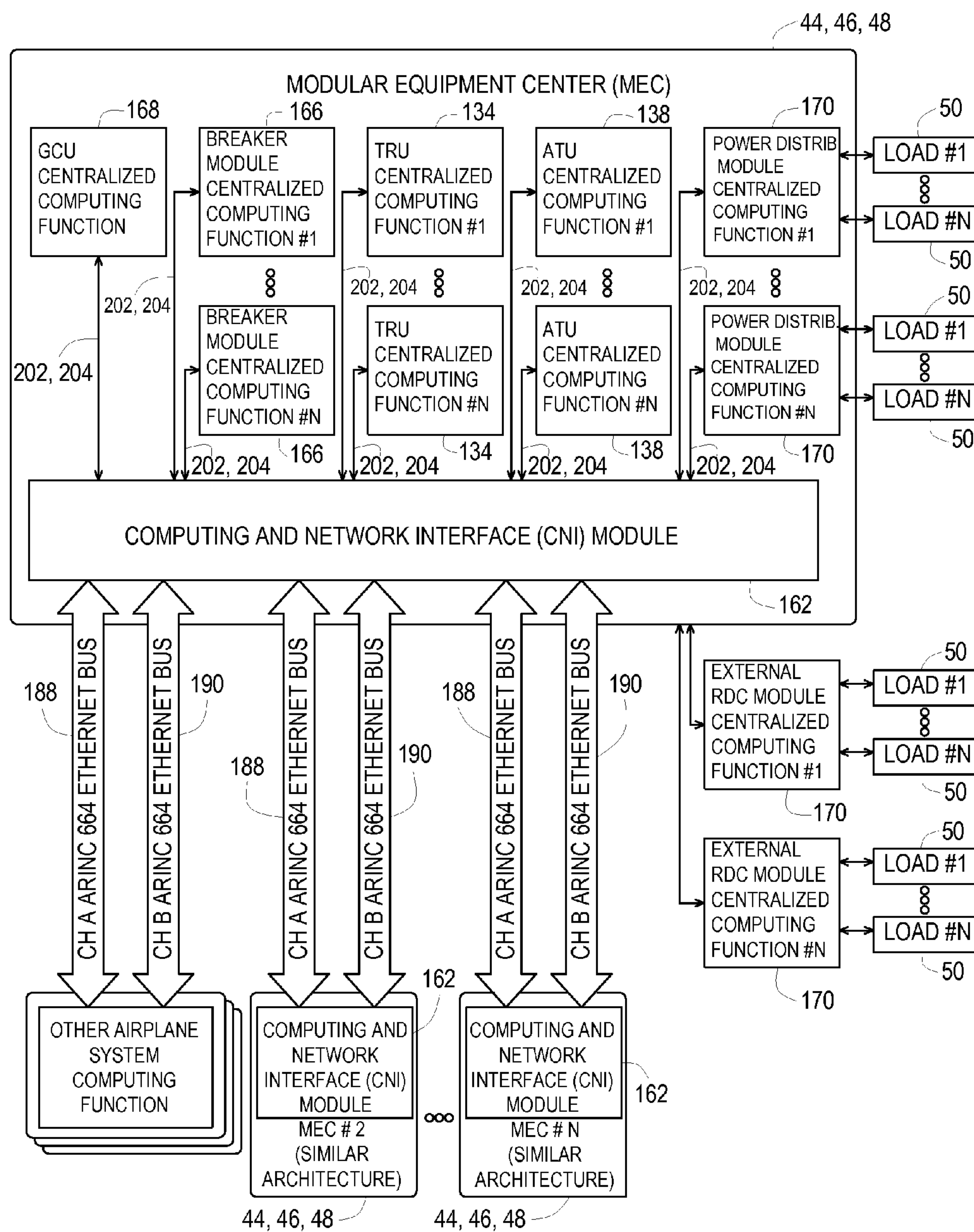


FIG. 7

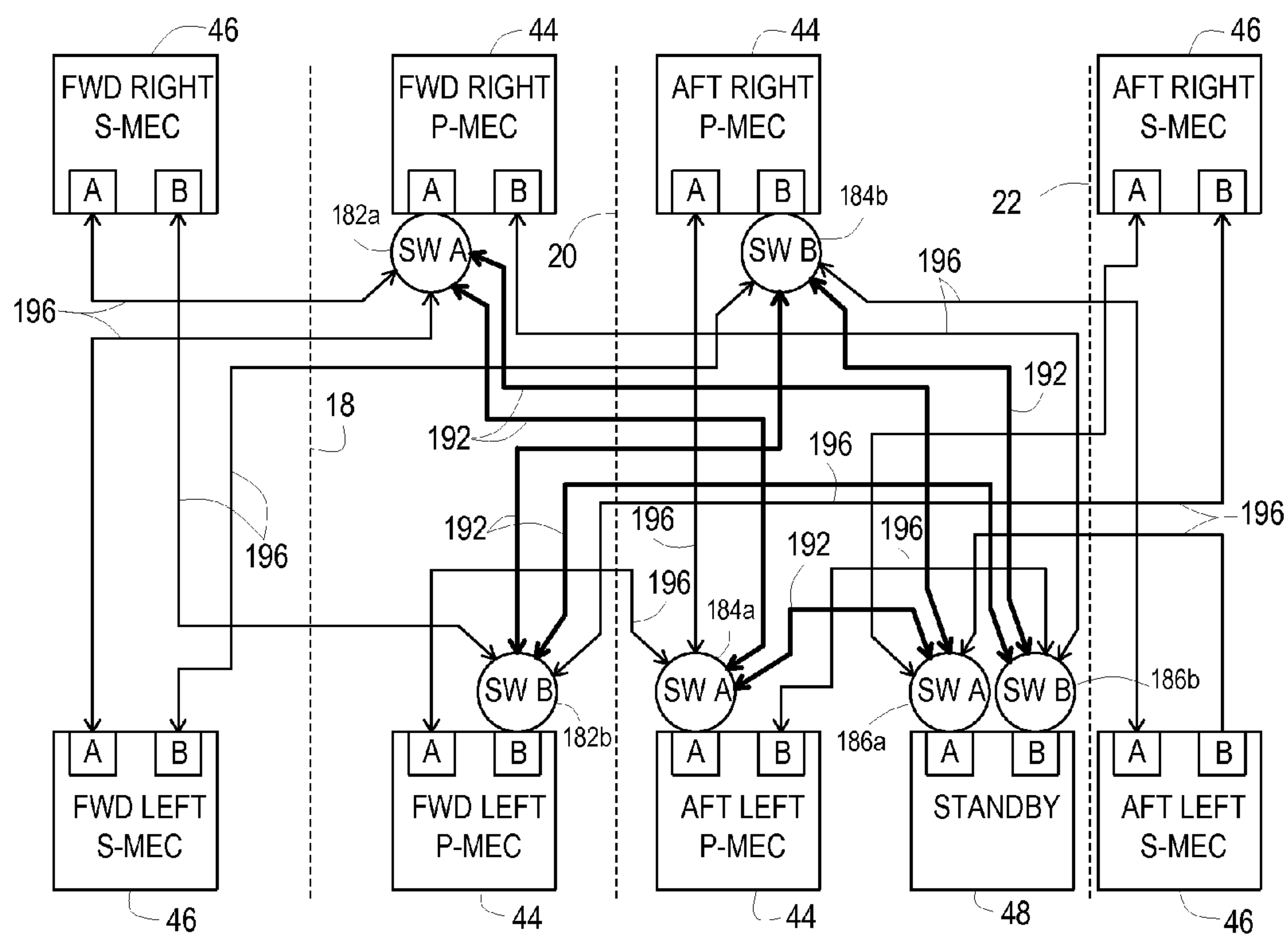


FIG. 8

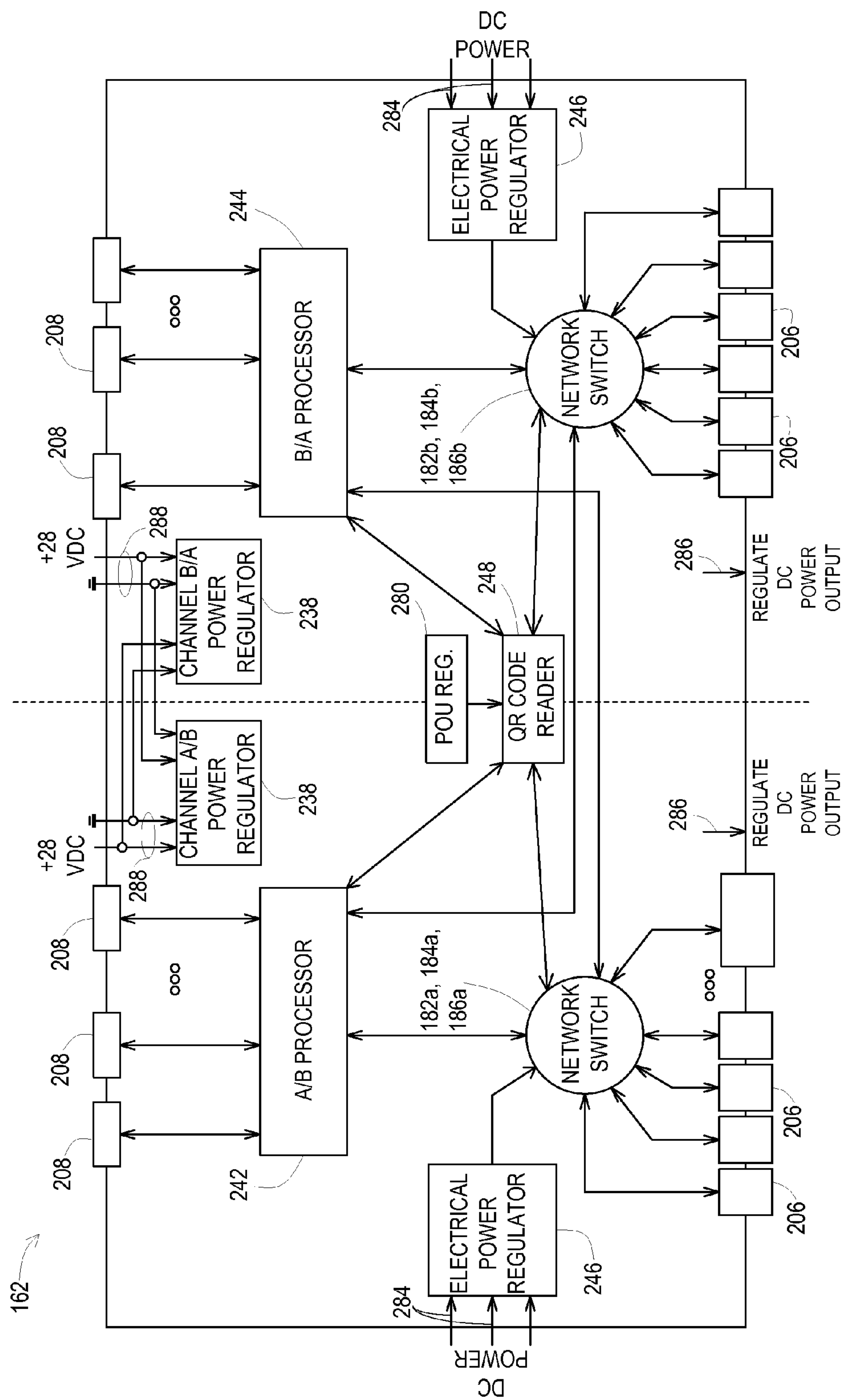


FIG. 9

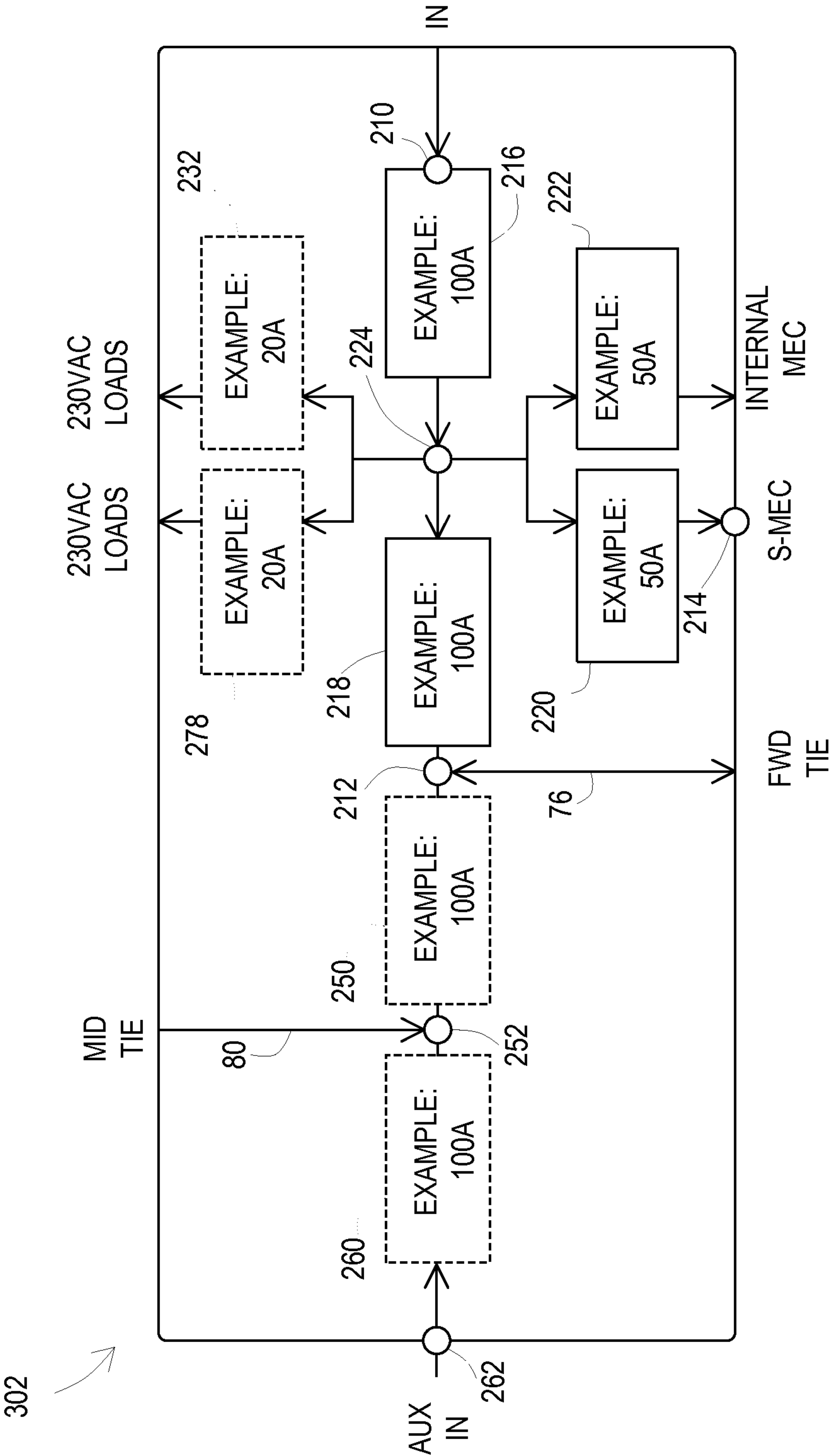


FIG. 10

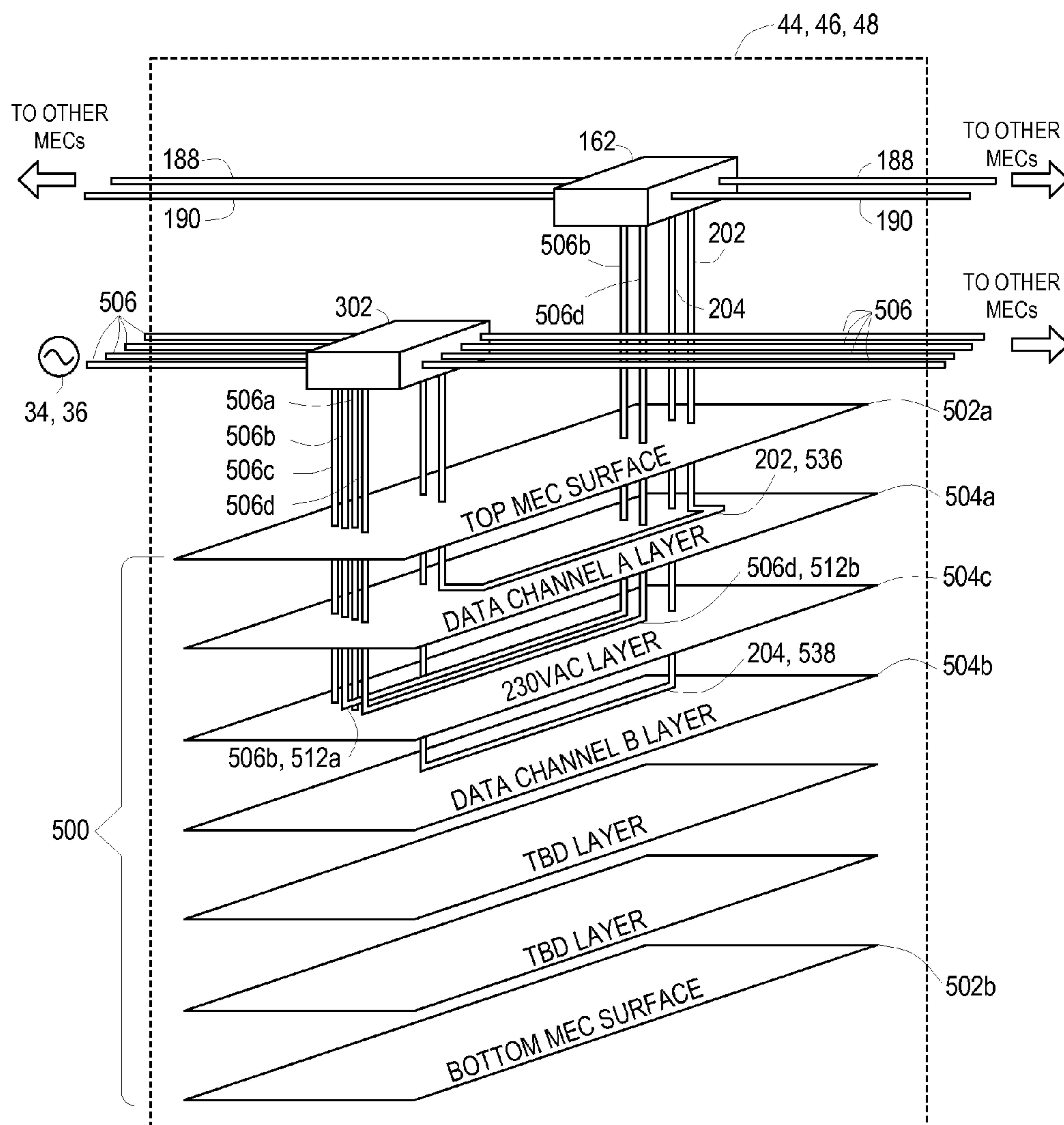


FIG. 11

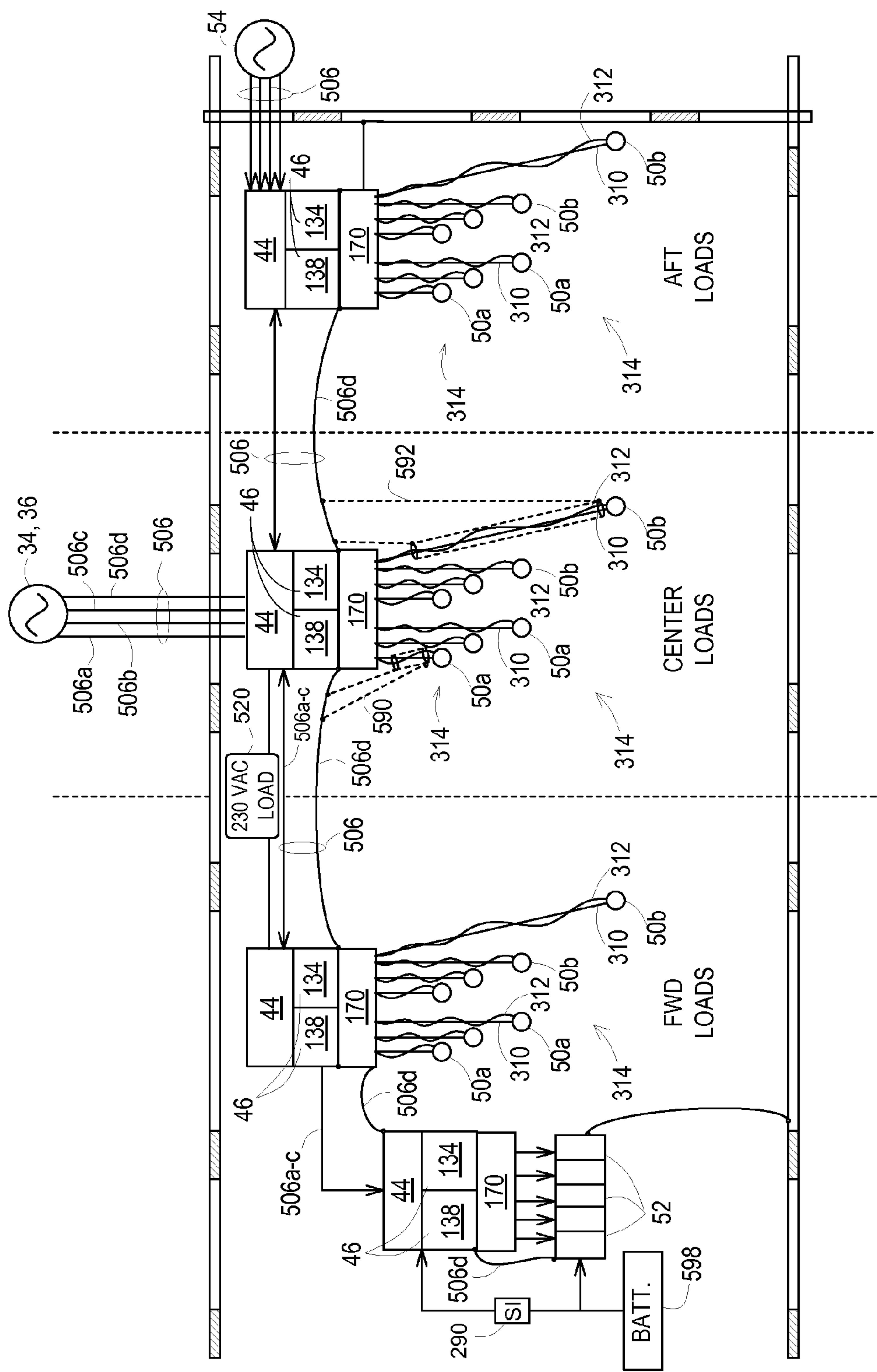


FIG. 12

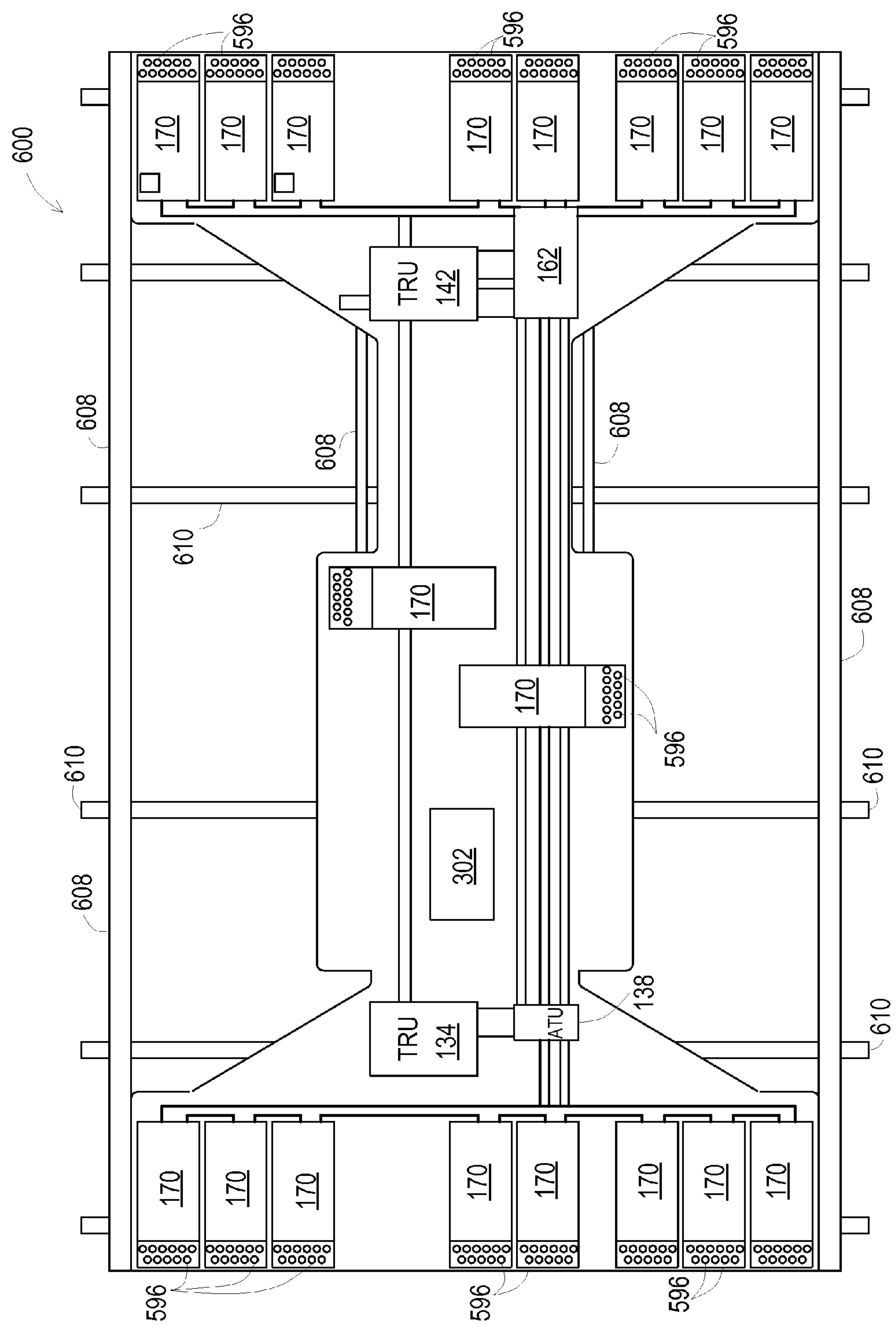


FIG. 13

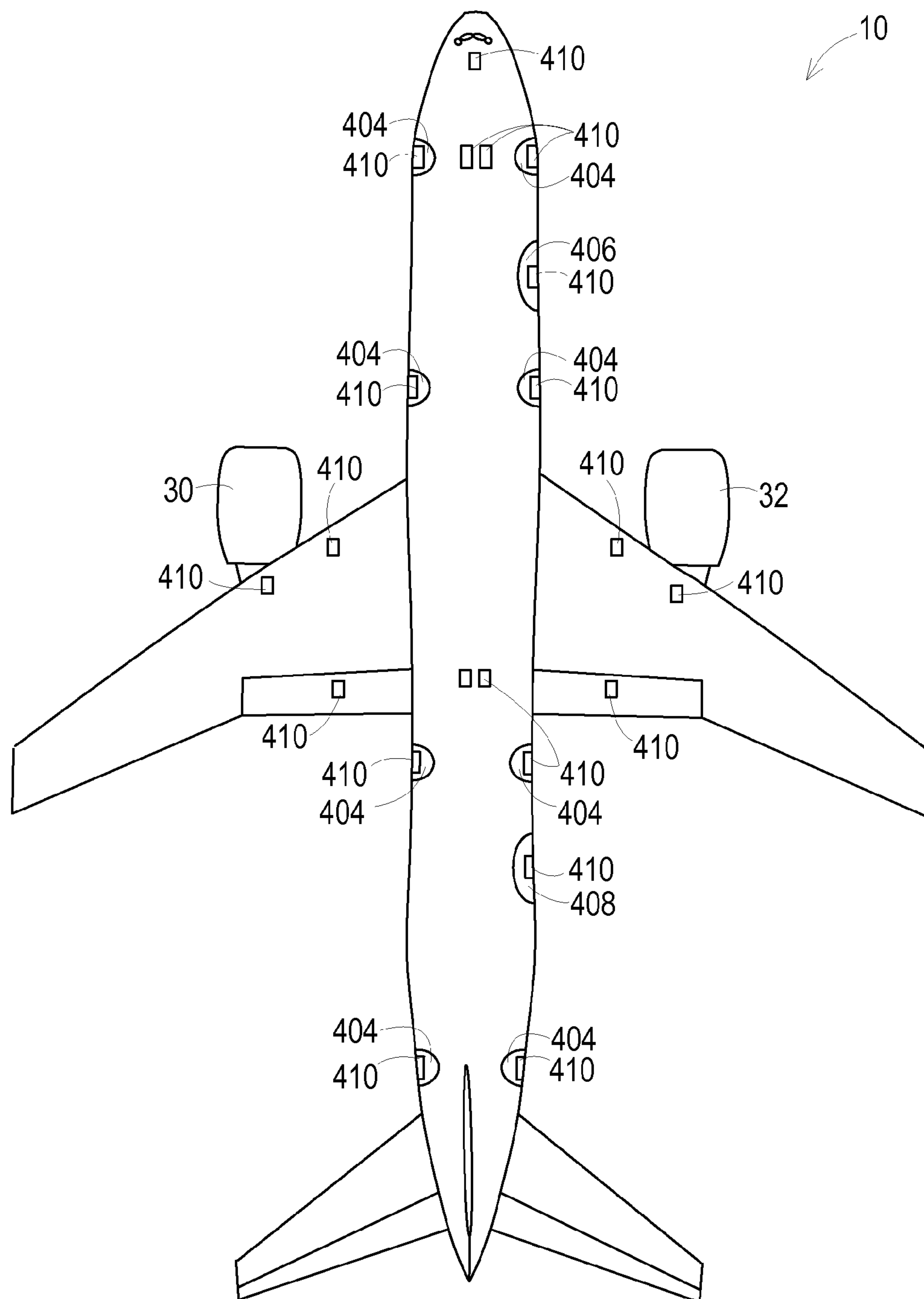


FIG. 14

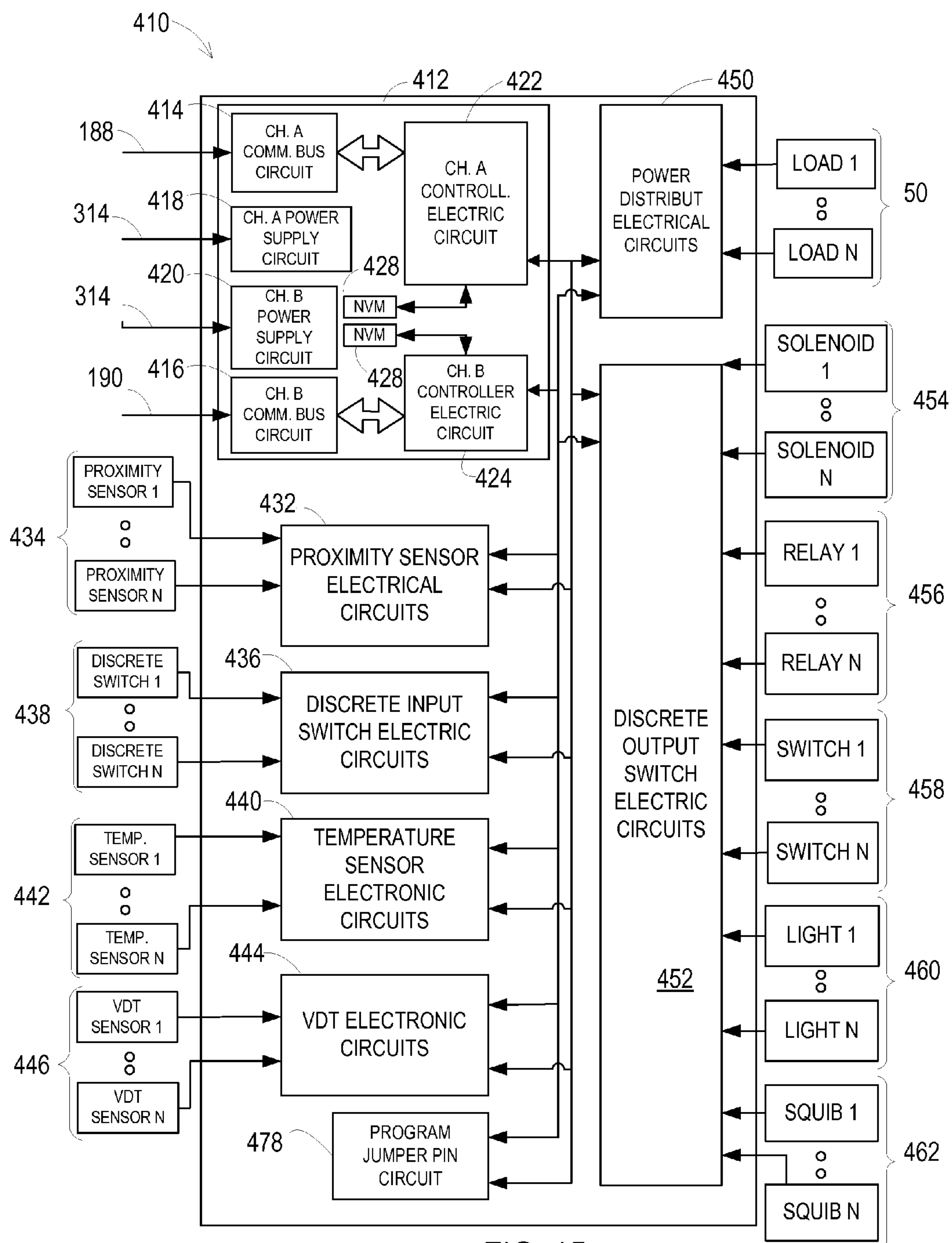


FIG. 15

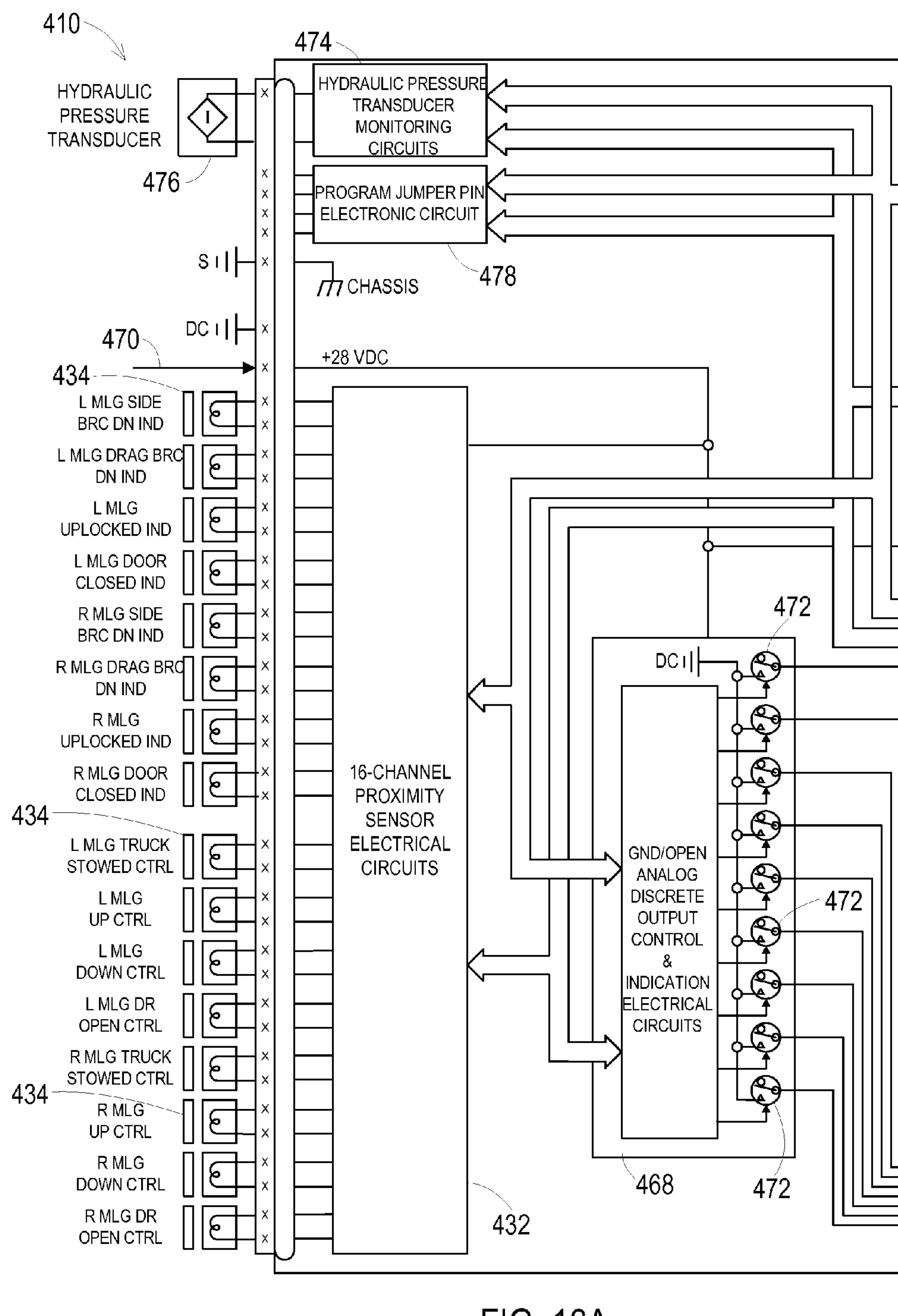


FIG. 16A

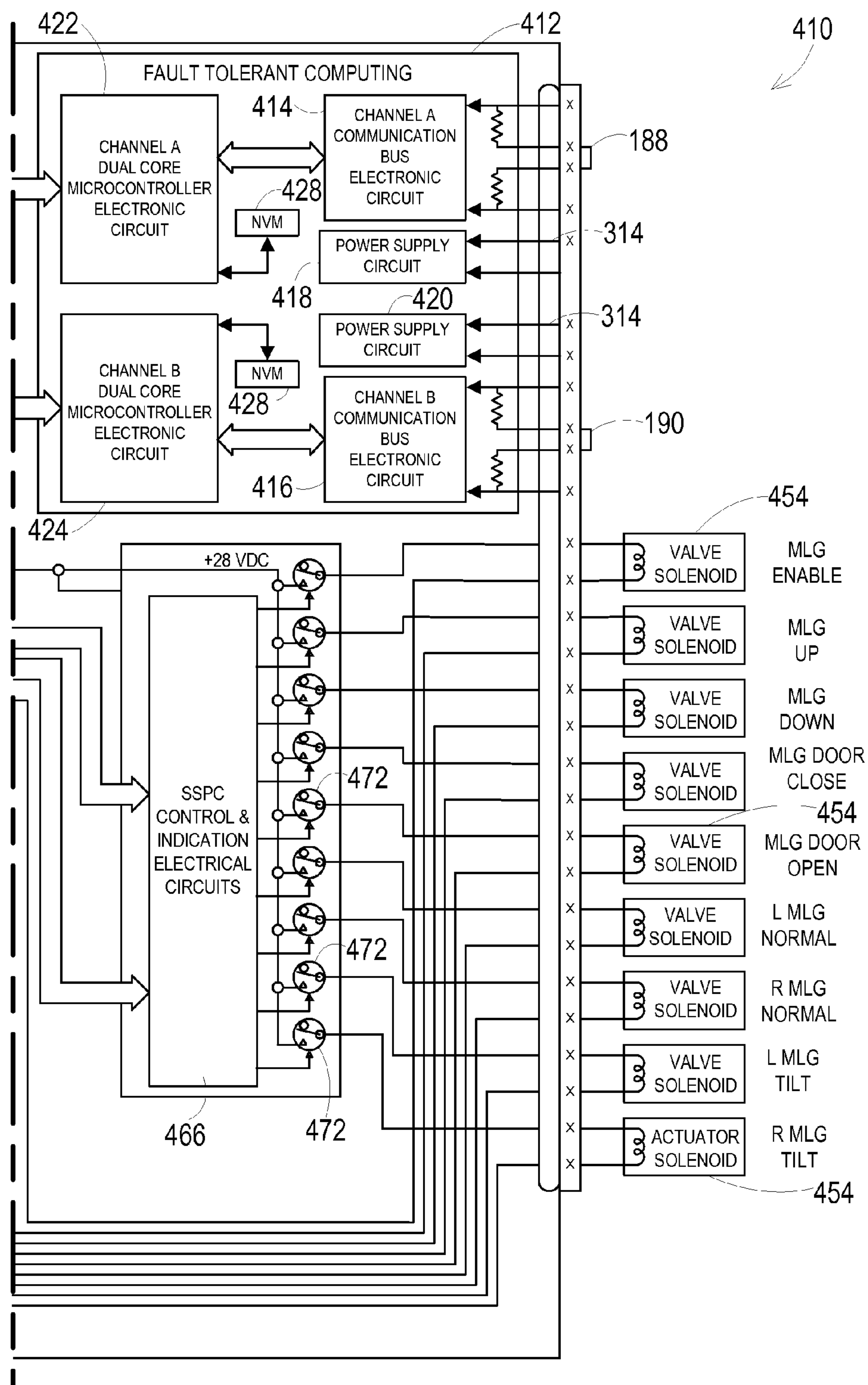


FIG. 16B

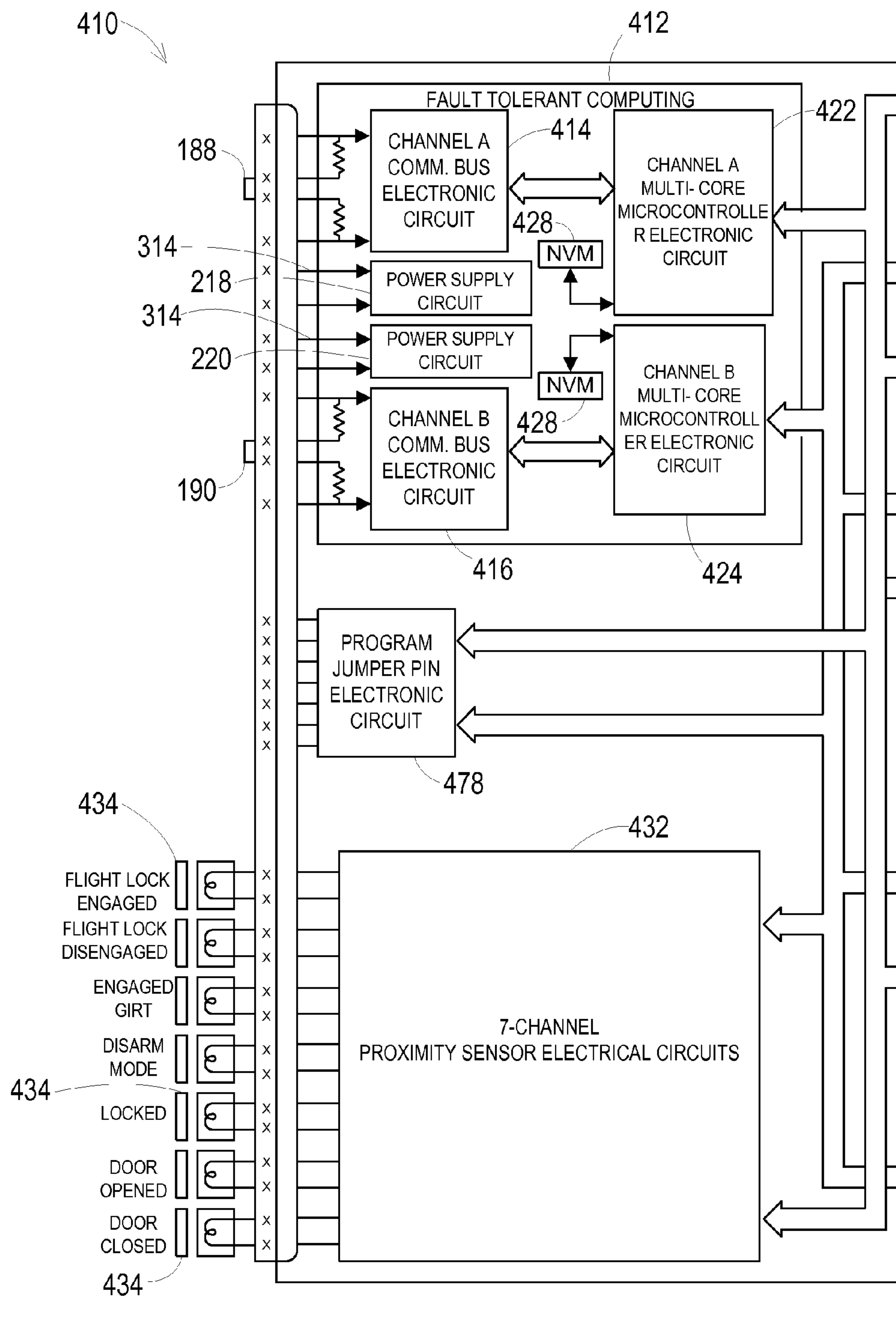


FIG. 17A

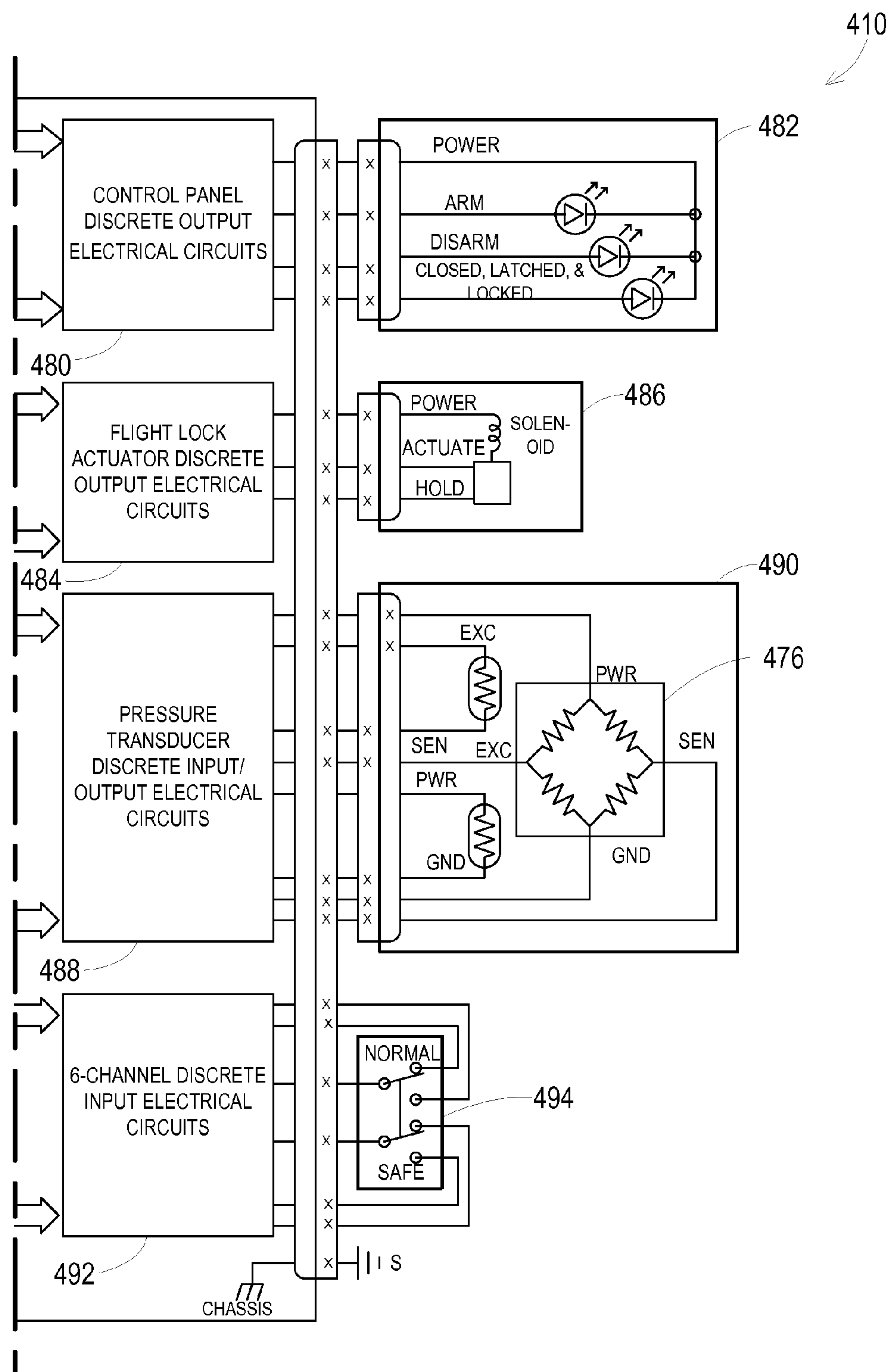


FIG. 17B

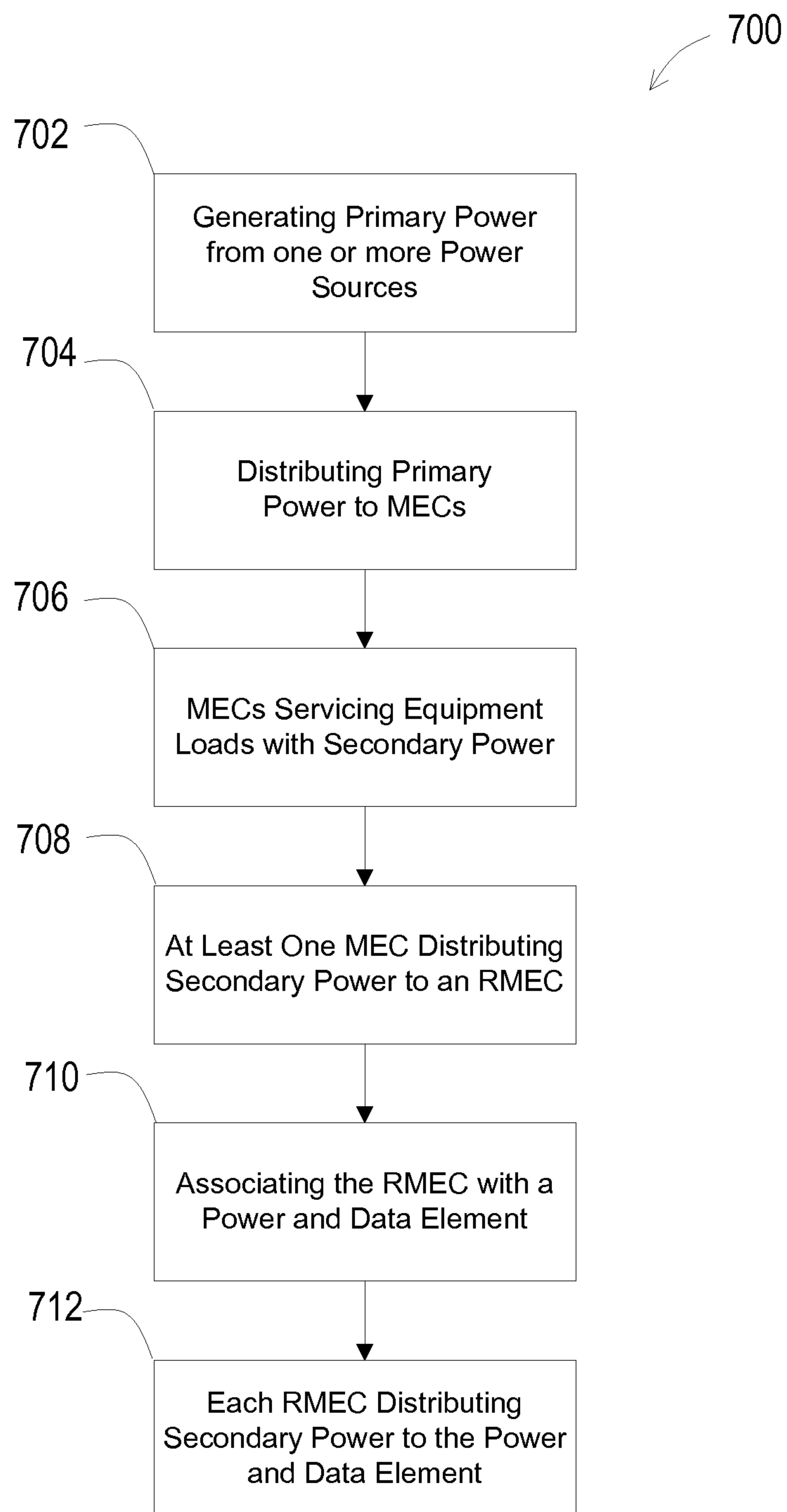


FIG. 18

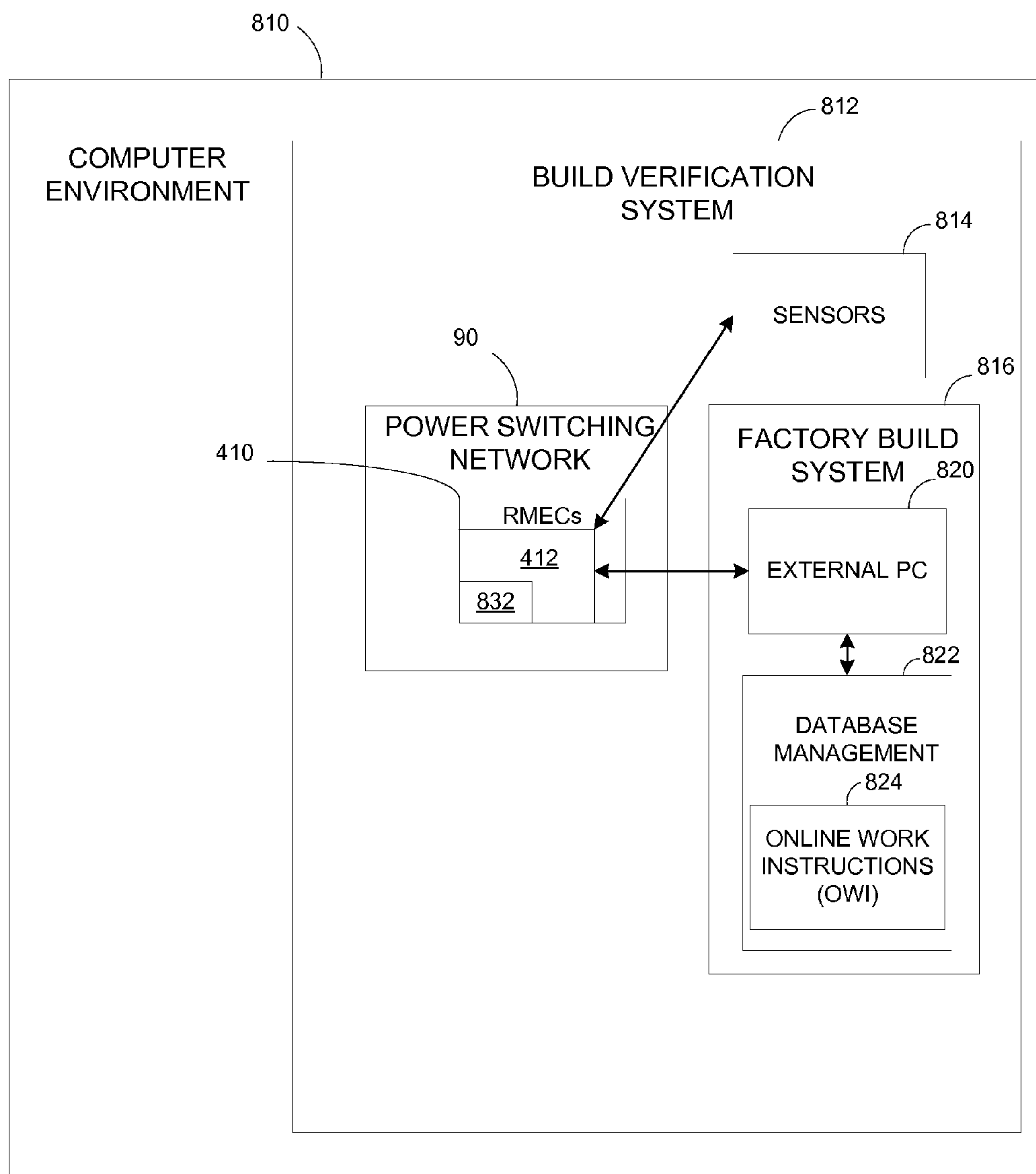


FIG. 19

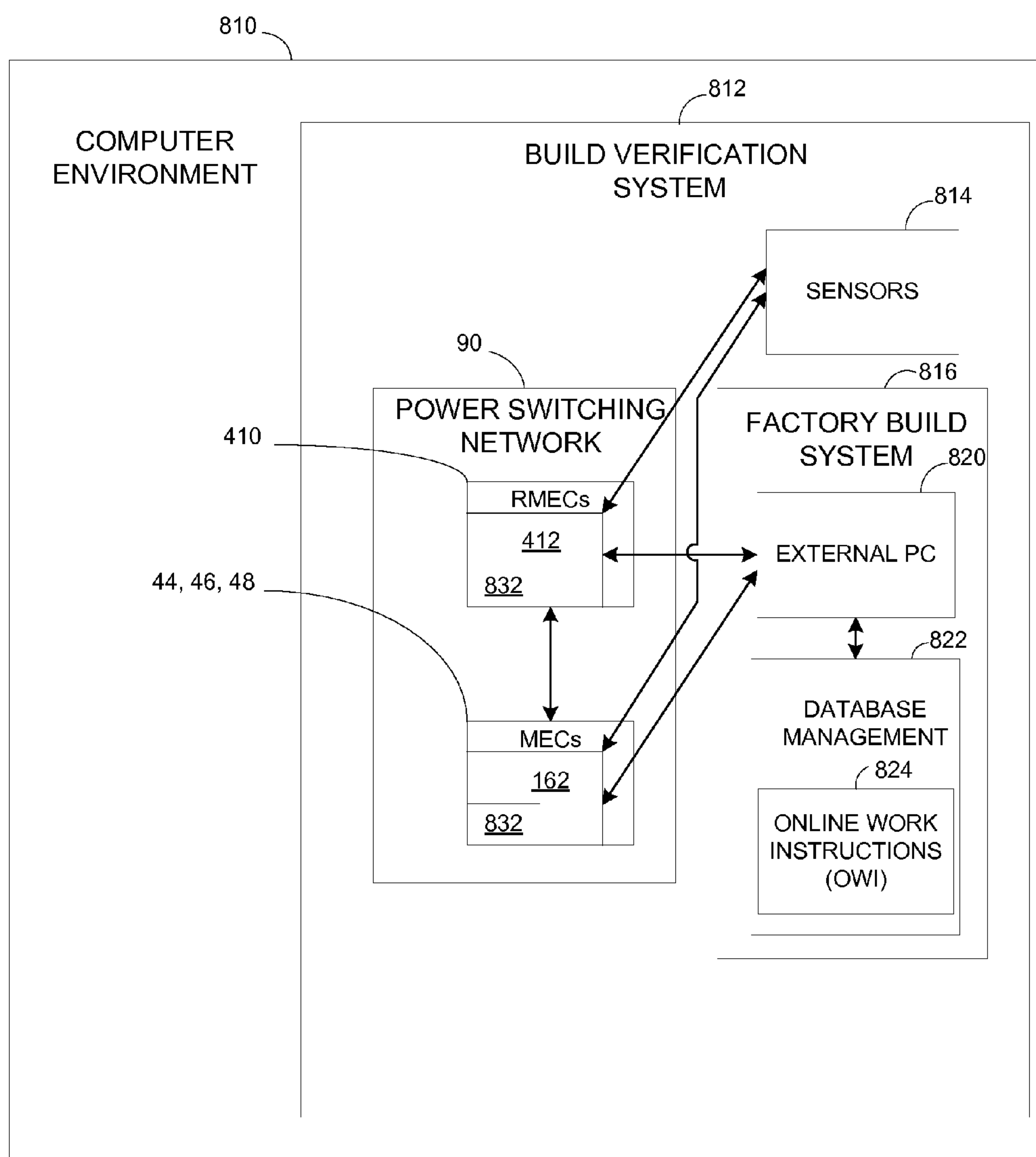


FIG. 20

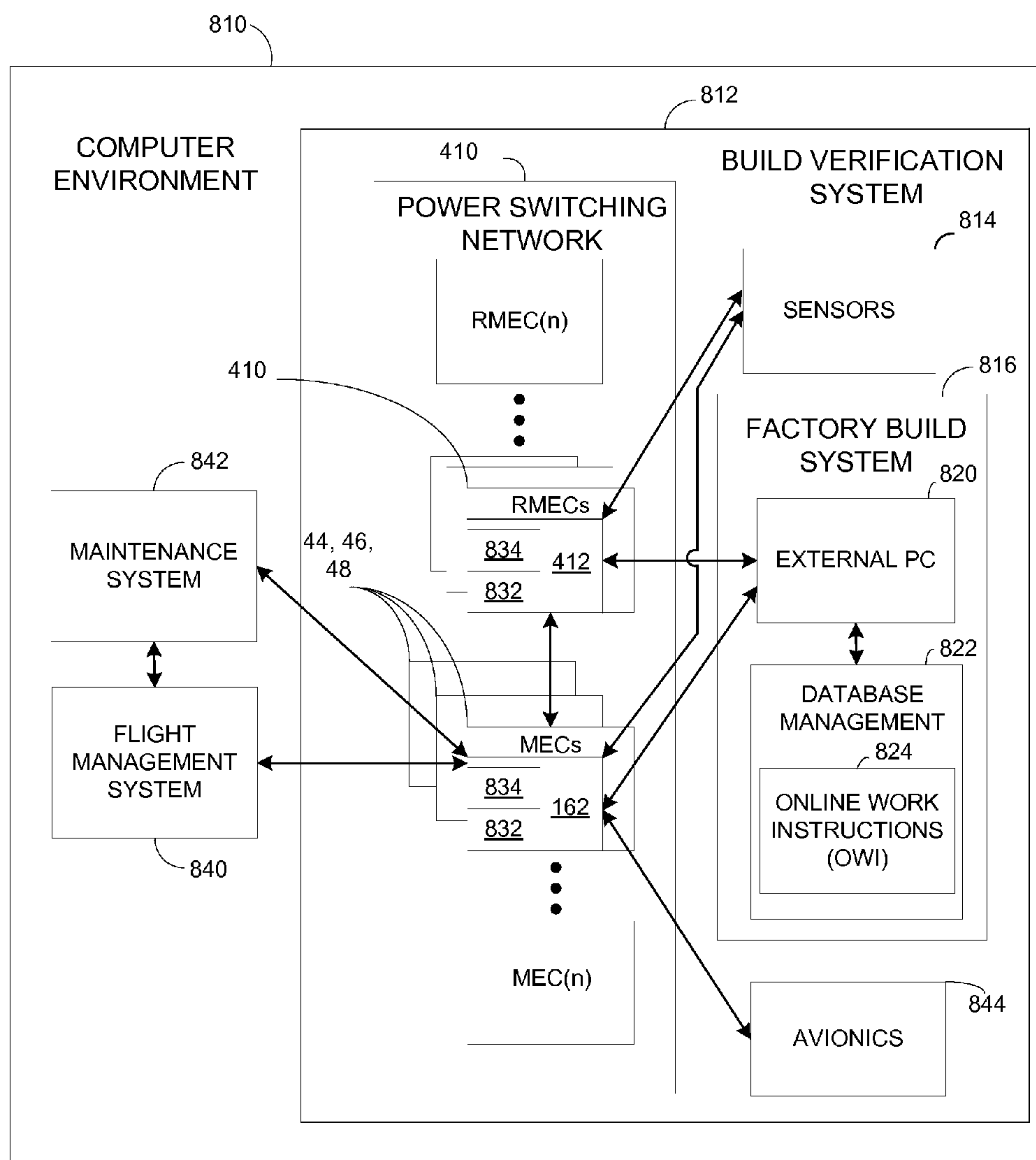


FIG. 21

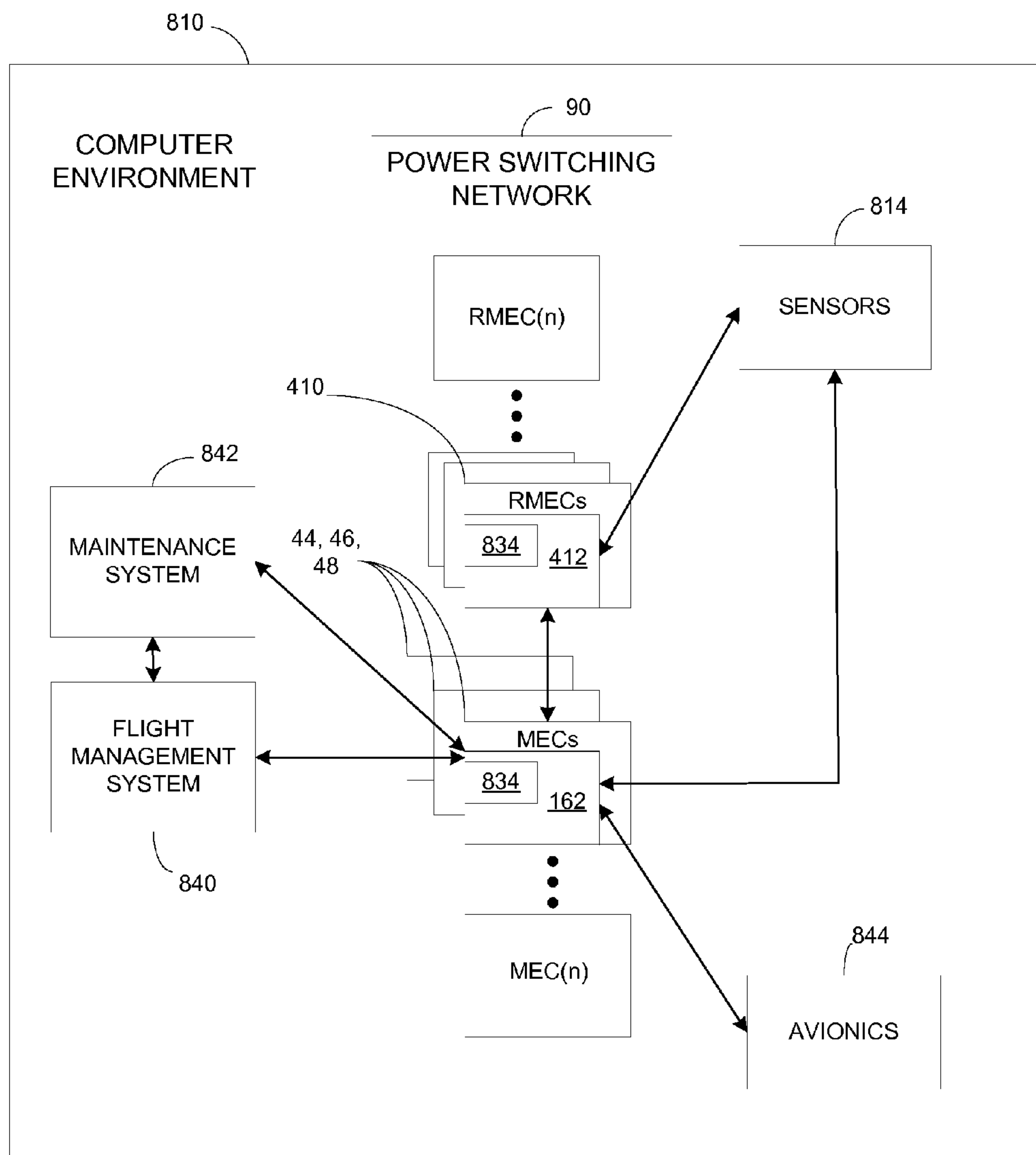


FIG. 22

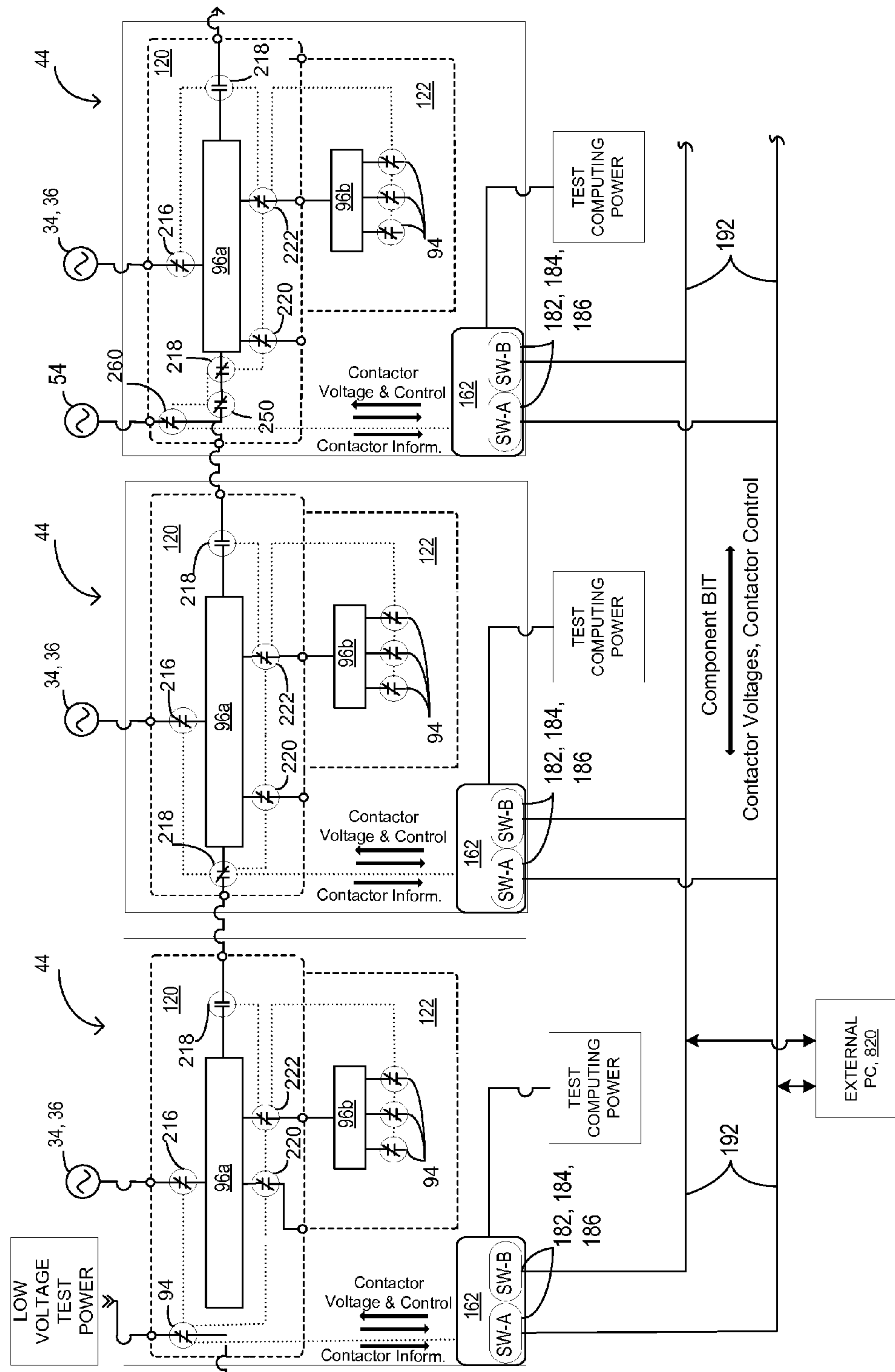


FIG. 23

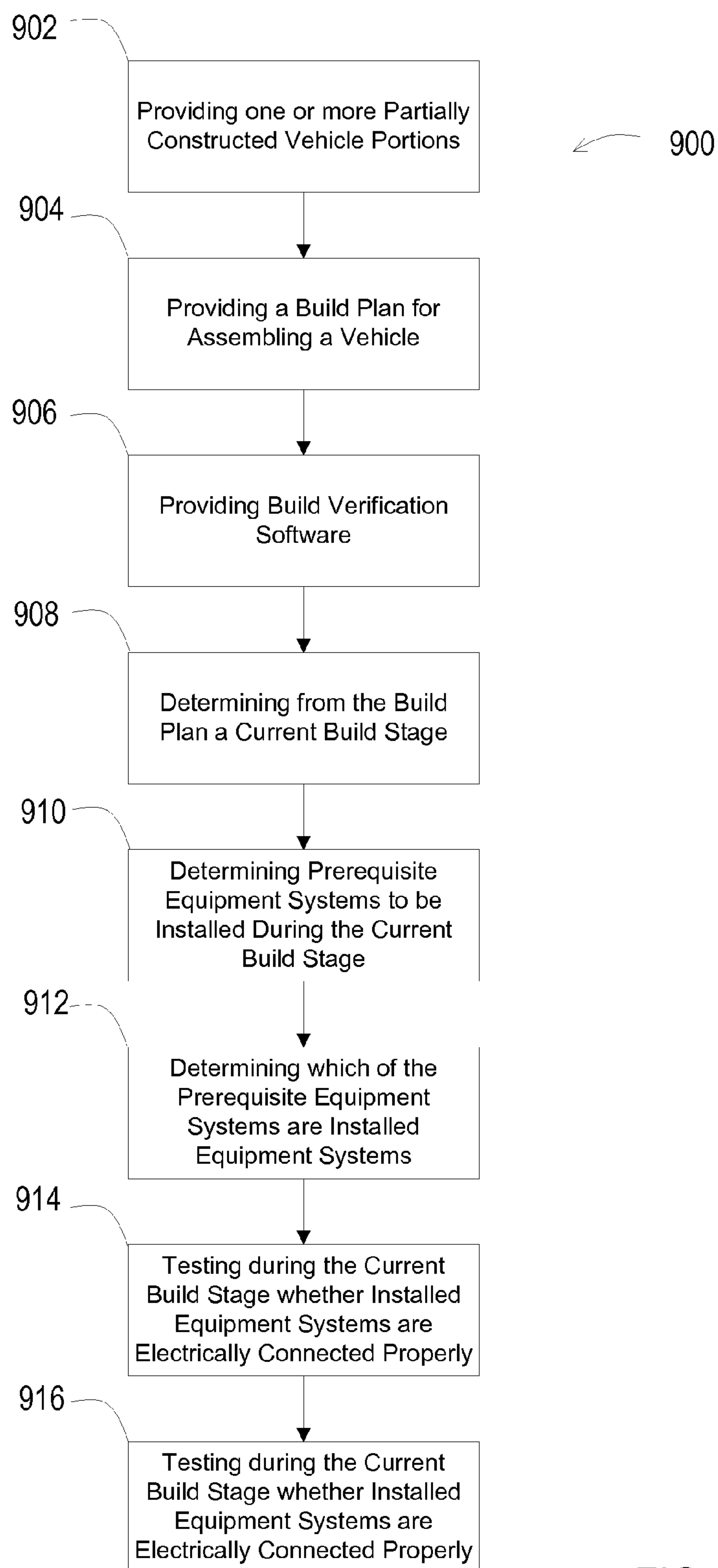


FIG. 24

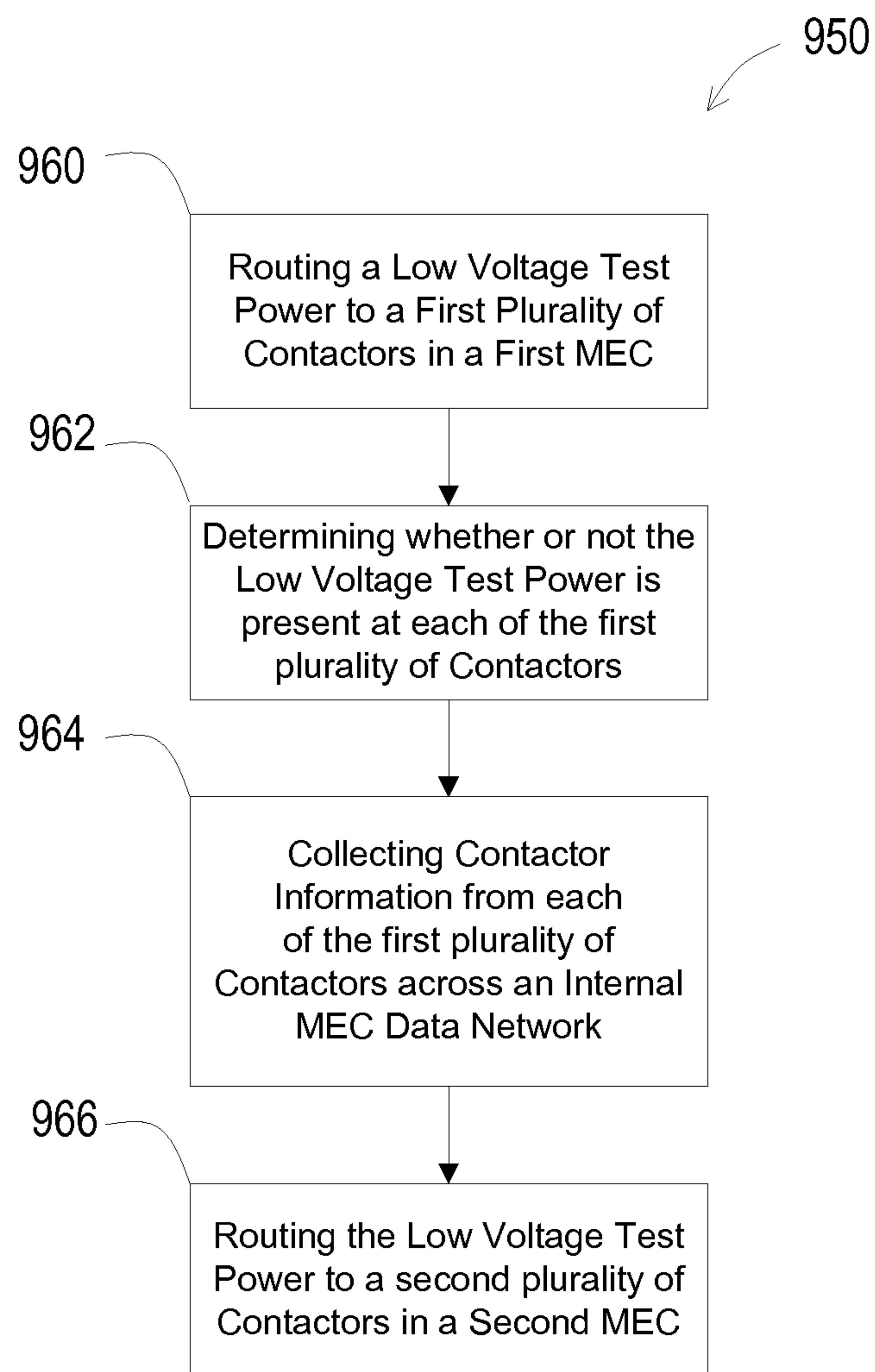


FIG. 25

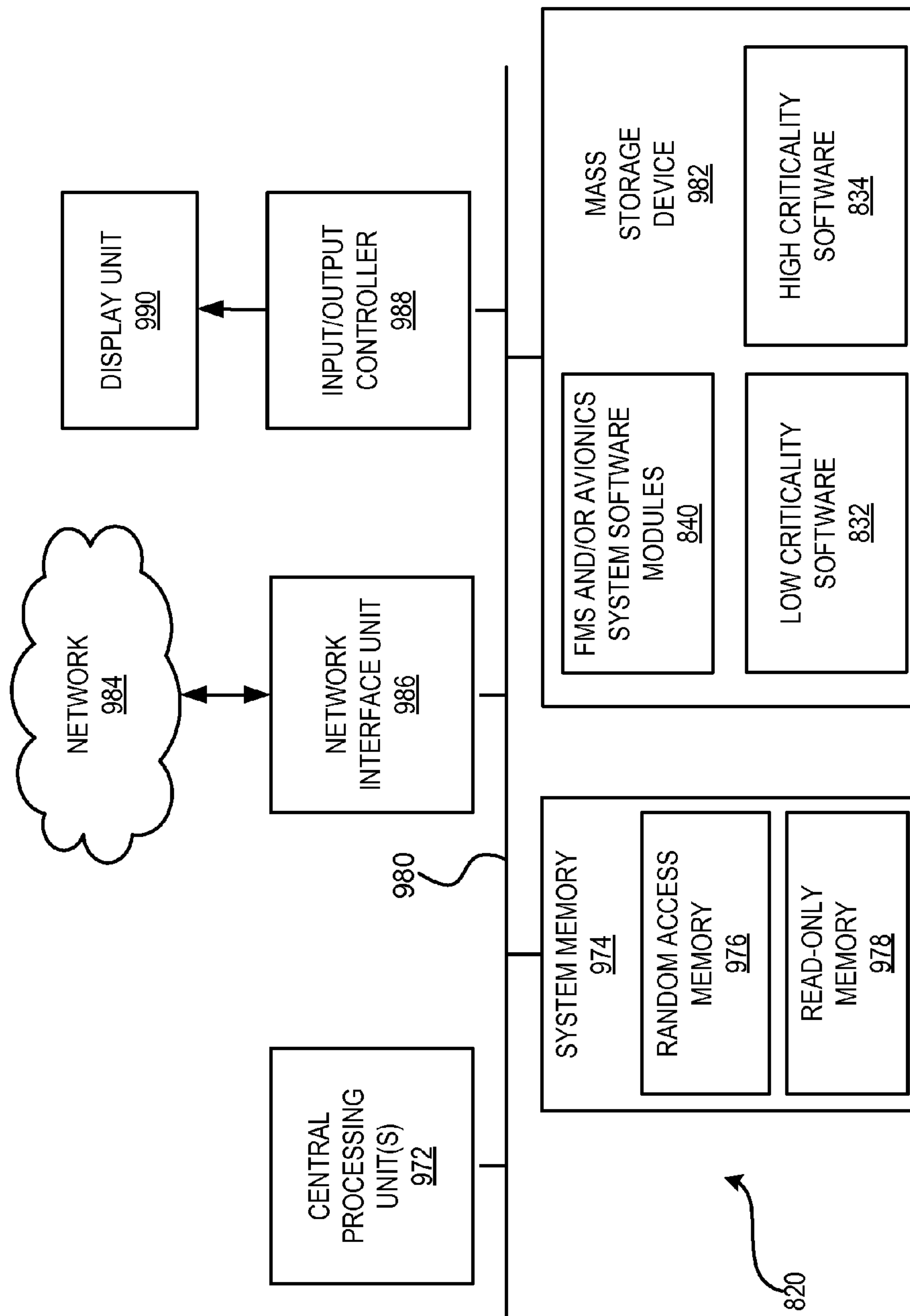


FIG. 26

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**SYSTEM AND METHOD FOR VEHICLE
BUILD VERIFICATION**

TECHNICAL FIELD

The field of the embodiments presented herein is directed toward vehicle build verification testing, and more particularly, to awareness of the build state of the vehicle and performing tests of installations during vehicle assembly.

BACKGROUND

Many commercial vehicles are manufactured by multiple vendors and each vendor may be responsible for building one or more portions of the vehicle. For example, the vehicle may be manufactured in separate sections and one vendor may be responsible for building one section and another vendor may be responsible for building another section. The separate sections are transported to a location where they are assembled together into a complete vehicle.

When manufacturing aircraft, the equipment systems delivered by vendors typically have final flight software pre-installed. This final flight software does not include any features to assist in the building of the aircraft. Built-in-test equipment (BITE) functionality is included in the hardware but the associated software is limited to fail-safe and maintenance concerns. This is useful when the aircraft is in service but not when the aircraft is being built.

Such vehicles are built according to a predetermined build plan developed to ensure that each completely assembled vehicle matches a certified design and will perform as designed. Administrative software referred to as factory build software within each manufacturing facility schedules and tracks the vehicle build as well as coordinates the inventory needed for each vehicle build. Factory build software typically includes online work instructions (OWIs) that identify what tasks need to be performed. An assembly line worker interfaces with the factory build software to sign off when each OWI is completed.

The build plan includes multiple phases or levels of the build that define a list of equipment systems and identify when they are to be installed. After an equipment system is installed, it is tested to verify that it is electrically installed correctly. Traditionally, an external test cart is rolled up to the aircraft section and numerous wiring connections are made manually to connect sensors within the external test cart to the equipment system being tested. In many cases, wiring bundles within the aircraft are opened up to make these connections to the external test cart. Power is applied from the external test cart to the wiring onboard the aircraft connected to the sensors on the external test cart to perform one or more tests. Software hosted by the external test cart performs the desired tests. For example, if the desired signals are sensed, then the connections are disconnected and reconnected manually elsewhere to perform additional tests. The external test cart is repeatedly connected and disconnected to verify the various equipment installations. Therefore, a factory build requires a significant amount of manual interaction and specialized equipment to verify correct equipment installations.

In an aircraft not all equipment systems within each section are self-contained. Most are intertwined with other sections of the aircraft. Therefore, to test and verify a section, the equipment systems that are not yet present in the build sequence would have to be emulated. Once equipment system installations have been tested, final assembly processes are performed that would make additional testing

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difficult due to limited accessibility. Aircraft could be built at a faster rate and orders for completed aircraft could be filled more quickly with the use of verification testing systems earlier in the build process.

It is with respect to these and other considerations that the disclosure herein is presented.

SUMMARY

It should be appreciated that this Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to be used to limit the scope of the claimed subject matter.

According to one embodiment disclosed herein, a computer-implemented method (where the computer comprise hardware and software) for verifying proper installation of equipment systems in a vehicle designed to be assembled in multiple build stages is provided. The method includes providing one or more partially constructed vehicle portions of the vehicle and providing a build plan for assembling the vehicle comprising a plurality of build stages. The method also includes providing build verification software configured for determining from the build plan a current build stage of at least one partially constructed vehicle portion, determining one or more prerequisite equipment systems to be installed in the one or more partially constructed vehicle portions according to the current build stage, determining which of the one or more prerequisite systems have been installed in the one or more partially constructed vehicle portions during the current build stage, thereby defining one or more installed equipment systems, and testing during the current build stage whether the one or more installed equipment systems are electrically connected correctly in the one or more partially constructed vehicle portions. The method may also include emulating prerequisite equipment systems that are not yet installed but are necessary for testing.

According to another embodiment disclosed herein, a system for verifying proper installation of equipment systems within one or more partially constructed vehicle portions is provided. The system includes a predetermined build plan having multiple build stages for assembling the one or more partially constructed vehicle portions. The system also includes prerequisite equipment systems to be installed within the one or more partially constructed vehicle portions. At least one of the prerequisite equipment systems configured to be installed during each of the build stages wherein each of the prerequisite equipment systems becoming installed equipment systems when installed in the one or more partially constructed vehicle portions. The system also includes build verification software configured to determine a current build stage of the plurality of build stages, which of the plurality of prerequisite equipment systems are to be installed during the current build stage, which of the plurality of prerequisite equipment systems that are to be installed during the current build stage but are not yet installed in the one or more partially constructed vehicle portions, and test electrical connectivity of the installed equipment systems in the one or more partially constructed vehicle portions to verify proper installation during each of the plurality of build stages.

According to yet another embodiment disclosed herein, a computer-readable storage medium is provided that includes instructions for determining a current build stage of one or more partially constructed vehicle portions from a plurality of build stages, instructions for determining prerequisite equipment systems to be installed in the one or more

partially constructed vehicle portions during the current build stage, instructions for determining which prerequisite equipment systems are to be installed during the current build stage that are not yet installed in the one or more partially constructed vehicle portions, and instructions for testing during each of the plurality of build stages whether at least one installed equipment system installed in the partially constructed vehicle portion is properly electrically connected within the one or more partially constructed vehicle portions.

According to still yet another embodiment disclosed herein, a computer-implemented method for verifying proper installation of equipment systems of a primary power bus network within a first modular equipment center (MEC) is provided. The method includes routing a low voltage test power to a first plurality of contactors within the first MEC, determining whether or not the low voltage test power is present at each of the first plurality of contactors of the first MEC, and collecting contactor information from each of the first plurality of contactors across an internal MEC data network of the first MEC to a computing and network interface (CNI) module of the first MEC.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments presented herein will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. 1 illustrates a top view of one configuration of an aircraft with spatially distributed modular equipment centers (MECs) wherein equipment loads are serviced by the nearest MEC according to at least one embodiment disclosed herein,

FIG. 2 illustrates the splitting of two generators per aircraft engine relative forward and aft of the aircraft according to at least one embodiment disclosed herein,

FIG. 3 illustrates one configuration of primary power feeders connected to generators energizing a power bus network according to at least one embodiment disclosed herein,

FIG. 4 illustrates one configuration of a primary MEC and a secondary MEC according to at least one embodiment disclosed herein,

FIGS. 5A-5F illustrate one configuration of a fault tolerant combined primary and secondary power distribution network of primary MECs, secondary MECs, and a standby MEC according to at least one embodiment disclosed herein,

FIG. 6 illustrates one configuration of a secondary power bus network in a forward section of the aircraft according to at least one embodiment disclosed herein,

FIG. 7 illustrates one configuration of a MEC for servicing equipment loads and having a computing and network interface module for distributed computing functions and gateway routing of bi-directional data between MECs according to at least one embodiment disclosed herein,

FIG. 8 illustrates one configuration of a data network structure with communication bus interfaces between spatially distributed MECs separated by section breaks according to at least one embodiment disclosed herein,

FIG. 9 illustrates one configuration of the computing and interface module for distributed computing functions and gateway routing of bi-directional data according to at least one embodiment disclosed herein,

FIG. 10 illustrates a common structure and layout of a primary power switching network device having a common power input source and a plurality of common power outputs for use with the primary MECs according to at least one embodiment disclosed herein,

FIG. 11 illustrates an exploded perspective view of a multi-layered integrated truss system of a MEC according to at least one embodiment disclosed herein,

FIG. 12 illustrates one configuration of the distribution of either alternating current (AC) or DC power from the TRUs and ATUs to equipment loads utilizing twisted and shielded electrical conductor pairs according to at least one embodiment disclosed herein,

FIG. 13 illustrates one configuration of an integrated truss system of a MEC within the floor of an aircraft according to at least one embodiment disclosed herein,

FIG. 14 illustrates one configuration of an aircraft having remote MECs (RMECs) throughout the aircraft in the pressurized and unpressurized portions of the aircraft according to at least one embodiment disclosed herein,

FIG. 15 illustrates one configuration of a block diagram of an RMEC having a fault-tolerant power and communication system and that is customizable based on the needs of an aircraft subsystem according to at least one embodiment disclosed herein,

FIGS. 16A and 16B illustrate one configuration of an RMEC for a landing gear control and indication system according to at least one embodiment disclosed herein,

FIGS. 17A and 17B illustrate one configuration of an RMEC on a passenger entry door of a passenger entry door system according to at least one embodiment disclosed herein,

FIG. 18 illustrates one configuration of a routine for providing power and data to remote power and data elements of a vehicle according to at least one embodiment disclosed herein,

FIG. 19 illustrates one configuration of a computer environment and a build verification system for use with one or more partially constructed vehicle portions having an RMEC according to at least one embodiment disclosed herein,

FIG. 20 illustrates one configuration of a computer environment and a build verification system for use with one or more partially constructed vehicle portions having an RMEC interfacing with a MEC according to at least one embodiment disclosed herein,

FIG. 21 illustrates one configuration of a computer environment and a build verification system for use with a fully assembled aircraft, prior to initial power up, having multiple RMECs interfacing with multiple MECs and a flight management system (FMS) according to at least one embodiment disclosed herein,

FIG. 22 illustrates one configuration of a computer environment and a build verification system for use with a flight-ready aircraft having a FMS but with the build verification system (BVS) removed according to at least one embodiment disclosed herein,

FIG. 23 illustrates one configuration of multiple MECs of a primary power switch network interfacing with one another wherein the CNI modules have embedded BVS software for verifying proper installation of the MECs by routing power to contactors within the MECs and collecting and sharing information about the contactors at the CNI modules according to at least one embodiment disclosed herein,

FIG. 24 illustrates one configuration of a routine for verifying proper installation of equipment systems in a

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vehicle designed to be assembled in multiple build stages according to at least one embodiment disclosed herein,

FIG. 25 illustrates one configuration of a routine for verifying proper installation of equipment systems of a primary power bus network within a MEC according to at least one embodiment disclosed herein, and

FIG. 26 illustrates one configuration of a block diagram showing an illustrative computer system capable of implementing aspects of the embodiments presented herein.

The plurality of figures presented in this application illustrates variations and different aspects of the embodiments of the present disclosure. Accordingly, the detailed description on each illustration will describe the differences identified in the corresponding illustration.

DETAILED DESCRIPTION

The following detailed description is directed to the manufacture and assembly of vehicles from multiple vehicle portions according to a build plan of multiple stages and the use of build verification software to test and verify that equipment systems are installed properly within the vehicle portions in such a way that reduces production time and such that the testing of the installed equipment systems is completed prior to delivery of the vehicle to the customer. The present invention is susceptible of embodiment in many different forms. There is no intent to limit the principles of the present invention to the particular disclosed embodiments. References hereinafter made to certain directions, such as, for example, “front”, “rear”, “left” and “right”, are made as viewed from the rear of the vehicle looking forward. In the following detailed description, references are made to the accompanying drawings that form a part hereof and in which are shown by way of illustration specific embodiments or examples. Referring now to the drawings, in which like numerals represent like elements throughout the several figures, aspects of the present disclosure will be presented.

Aspects of this disclosure may be used in many types of vehicles such as, for example, aircraft, spacecraft, satellites, watercraft, submarines, and passenger, agricultural or construction vehicles. Aspects of this disclosure may also be used in different constructions of vehicles. While the immediate benefit is towards vehicles that have non-conducting frames, chassis or skin, the disclosure features may be suitable and beneficial of vehicles constructed of conductive materials. For the sake of simplicity in explaining aspects of the present disclosure, this specification will proceed utilizing a composite aircraft 10 as the primary example. However, as will be seen, many of aspects of the present disclosure are not limited to the composite aircraft 10.

As well understood by those skilled in the art, the exemplary aircraft 10 depicted in FIG. 1 includes a body commonly referred to as a fuselage that is made substantially of composite materials, or composites. The outer composite skin on the fuselage of the aircraft 10 conforms to the curvature of fuselage frames. The fuselage includes a plurality of vehicle sections such as a forward section 12, a middle section 14, and an aft section 16. Section breaks 18, 20, 22 are defined between adjacent aircraft sections. The composite aircraft 10 may have any number of engines. As shown in FIG. 1, left engine 30 is supported on the left wing and right engine 32 is supported on the right wing. Each of the engines 30, 32 has a rotor which defines a rotor burst zone 38 (FIG. 5A) in which damage to the fuselage and

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aircraft systems between the engines 30, 32 may occur as a result of an event or an operational inconsistency with one of the engines 30, 32.

The composite aircraft 10 may have any number of sections and the position of the aircraft sections or systems within the composite aircraft 10 may sometimes be described as being forward or aft of the rotor burst zone 38. Floor beams extend between fuselage frames to define a passenger compartment above the floor beams and a cargo area for holding cargo below the floor beams. Stanchions extending between the fuselage frames and the floor provide a fulcrum to assist in stiffening the floor of the composite aircraft 10. The passenger area is pressurized and all or part of the cargo area may be pressurized. Ducts may be positioned through the crown run of the composite aircraft 10 above the passenger compartment or below the floor in the cargo area such as between the fuselage frame and the stanchions.

On each of the engines 30, 32 are one or more main primary power sources such as high voltage AC left power generators 34a, 34b and high voltage AC right power generators 36a, 36b (hereinafter may be referred to collectively and/or generically as “left generators 34”, “right generators 36” or “generators 34, 36”). Primary power feeders 40a and 40b extend from the left generators 34a, 34b and primary power feeders 42a and 42b extend from the right generator 36a, 36b. As shown in FIG. 1, primary power is distributed throughout the composite aircraft 10 via the primary power feeders 40a, 40b, 42a, 42b (hereinafter may be referred to collectively and/or generically as “power feeders 40, 42”). The composite aircraft 10 may also have one or more high voltage AC auxiliary power unit generators 54 for redundancy in the event one or more of the generators 34, 36 fail, as well as to provide power when the engines 30, 32 are not running. When the composite aircraft 10 is parked and the engines are not running, power may be provided to the aircraft by one or more power sources such as low voltage AC external power unit 56.

For purposes of this disclosure, low voltage and high voltage are those voltages typically referred to as either low or high voltage within the aircraft industry and as may be described in DO-160, Environmental Conditions and Test Procedures for Airborne Equipment, a standard for environmental test of avionics hardware published by RTCA, Incorporated. Throughout this disclosure, 230 VAC is referred to as high voltage but another voltage within a range of voltages, higher or lower than 230 VAC, could also be referred to as high voltage. Also, 28 VDC and 115 VDC are referred to as low voltages but another voltage within a range of voltages, higher or lower than either of 28 VDC and 115 VDC, could also be referred to as low voltage.

The composite aircraft 10 in FIG. 1 does not have dedicated centralized equipment bays for housing power and communications equipment. The equipment is configured into modular power and communication equipment centers, referred to as MECs, that are spatially distributed throughout the composite aircraft 10. For example, one or more MECs are spatially distributed in each of the forward, middle and aft sections 12, 14, 16. Each of the MECs provide localized power conversion and may be either a primary MEC 44, a secondary MEC 46, or an auxiliary or standby MEC 48, as described in greater detail below. Primary MEC 44, secondary MEC 46 and standby MEC 48 may generally be referred to as “MEC” with one or more applicable reference numbers 44, 46, 48. Primary power is distributed from the generators 34, 36 via power feeders 40, 42 across section breaks 18, 20, 22 to a primary power input of each of the MECs 44, 46, 48.

For optimized fault tolerance, the aircraft 10 may include a standby MEC 48 positioned in the rear of the aircraft 10 and at least two MECs 44, 46 positioned in each of the forward, middle, and aft sections 12, 14, 16 of the aircraft 10. For example, in FIG. 1 redundancy may be achieved by having multiple MECs 44, 46, 48 in each aircraft section without having to cross section breaks 18, 20, 22. Preferably, each section 12, 14, 16 includes a primary MEC 44 and a corresponding secondary MEC 46 thereby defining a two by three configuration of MECs 44, 46 plus a standby MEC 48. If there are four separate aircraft sections then there is a two by four configuration of MECs 44, 46. Preferably, the MECs 44, 46, 48 are alternately spaced on the left and right sides relative to one another along the length of the aircraft 10. It should be understood that the present disclosure is not limited to any particular number or configuration of MECs 44, 46, 48.

Equipment loads 50 may be various electrical loads in an aircraft including, but not limited to, displays, fans, environmental units, and the like. Sometimes an equipment load 50 may be in the form of a line replaceable unit (LRU) 52 (FIG. 4). The equipment loads 50 within each of the aircraft sections 12, 14, 16 are grouped into one or more zones of power and communication. Each zone of equipment loads 50 across multiple systems may be associated with and serviced by the nearest MEC 44, 46. Preferably, each zone of equipment loads 50 is located within a single section and associated with at least one MEC location in the same zone. Preferably, the connecting wires or lines do not cross section breaks 18, 20, 22.

Generally, any equipment load 50 on the aircraft 10 requires both electrical power and communication data. Data is needed to tell the equipment load 50 what to do, or provide feedback about its current status, while electrical power is needed so the equipment load 50 can perform its intended function. If power and data are provided to an equipment load 50 from different equipment centers and if one of either the power or data is lost then the equipment load 50 then has an indeterminable state. To avoid indeterminate states each MEC 44, 46, 48 independently provides both the electrical power and communication data for servicing each of the localized equipment loads 50 within an associated zone. The electrical power and data communication to an equipment load 50 may be synced or grouped together in that both the power and the data communication provided to the equipment load 50 originate from a single source such as the nearest MEC 44, 46, 48. Synced electrical power and communication data is sometimes referred to as a power channel. Each of the equipment loads 50 within a zone may receive power from a particular MEC 44, 46 and therefore the network communication switches providing data to those same equipment loads 50 are powered by that same MEC 44, 46.

The MECs 44, 46, 48 are configured to distribute power received from the main power sources. The MECs 44, 46, 48 may independently convert the primary power into secondary power. Secondary power may be distributed from the MECs 44, 46, 48 to then independently service each of the equipment loads 50 within each zone without a secondary branch power network extending across the section breaks 18, 20, 22. In such case, control and conversion of the primary power may be distributed to each of the primary MECs 44 of each section of the aircraft 10 such that only primary power is distributed across the section breaks 18, 20, 22 amongst the primary MECs 44. In a preferred configuration, only high voltage power feeders and the data backbone cross production breaks.

Distributing only primary power across section breaks 18, 20, 22 reduces the amount of wire required for distributing secondary power across multiple sections of the aircraft 10. This is because the distributed MEC architecture creates a separate secondary power distribution network within each section that allows for shorter runs of secondary wiring. Doing so reduces the overall weight of the wire utilized throughout the aircraft as well as the number of secondary connections required when joining adjacent fuselage sections. Also, because of the shorter secondary power runs, the total loop area of the power feeder run is reduced as compared to an implementation within a current return network. Moreover, aircraft production processes are improved because the secondary power network of wires extending across section breaks are limited or eliminated. The reduction of secondary power wires extending across section break are more readily tested and build quality verified earlier due to reduced reliance on other sections before final assembly of the aircraft 10.

As shown in FIG. 1, primary power feeder 40a extends from generator 34b on the left engine 30 into the middle section 14 to a MEC 44 shown on the left side of the middle section 14, across section break 20 to another MEC 44 shown on the left side of forward section 12, and then to another MEC 44 shown on the left side in front of forward section 12. Primary power feeder 40b extends from generator 34a on the left engine 30 into the middle section 14 to a MEC 44 on the left, across section break 22 to a left aft MEC 44, and then to a left aft MEC 48. Power feeder 42a extends from generator 36a on the right engine 32 into the middle section 14, across section break 20 to a MEC 44 on the right in forward section 12, and then to another MEC 44 on the right in front of the forward section 12. Primary power feeder 42b extends from generator 36b on the right engine 32 into the middle section 14 to middle right MEC 44, across section break 22 to right aft MEC 44, and then to right aft MEC 44. Alternatively, the power feeders 40a, 40b could instead provide primary power to the MECs 44 on the right side of one or more sections of the aircraft 10. In such case, the power feeders 42a, 42b would provide primary power to the MECs 44 on the left side of one or more sections the aircraft 10.

Also, one of the generators 34a, 34b on the left engine 30 could provide primary power to one side of the aircraft forward of a rotor burst zone 38 and the other of generators 34a, 34b on the left engine 30 could provide primary power to the other side of the aircraft 10 aft of the rotor burst zone 38. In such case, one of the generators 36a, 36b on the right engine 32 could provide primary power forward of the rotor burst zone 38 to the opposite side that is powered by one of the left generators 34a, 34b. The other of generators 36a, 36b on the right engine 32 could provide primary power aft of the rotor burst zone 38 to the opposite side powered by the other one of the left generators 34a, 34b.

FIG. 2 illustrates splitting two generators per engine relative the rotor burst zone 38 of the aircraft 10 which increases the availability of primary power in the event of an operational issue with an engine 30, 32. If one of the engines 30, 32 is lost, or a generator 34a-b, 36a-b within one of the engines 30, 32 fail, the two remaining generators 34a, 34b, 36a, 36b on the remaining engine 30, 32 distribute both forward and aft primary power to the aircraft 10. Generator 34a of the left engine 30 and generator 36a of the right engine 32 power a pair of primary power switching buses 96a forward of the rotor burst zone 38 that are connected to one another by a forward tie bus 76. Generator 34b of the left engine 30 and generator 36b of the right engine 32 power

another pair of primary power switching buses **96a** aft of the rotor burst zone **38** that are connected by an aft tie bus **78**. A mid tie bus **80** connects at least one of the forward primary power switching buses **96a** with at least one of the aft primary power switching buses **96a**. Therefore, when an engine **30, 32** experiences an operational inconsistency, the aircraft **10** continues to have power and control on one side along the entire length of the aircraft **10** due to the distribution of power from the remaining engine **30, 32** in a forward and aft manner. The power and control is distributed from a single engine **30, 32** both forward and aft of the rotor burst zone **38** without increasing the amount of wiring. FIG. 2 also illustrates the primary power switching buses **96a** distributing power to the secondary MECs **46** for power conversion and distribution to equipment loads **50** as explained in greater detail below. A standby MEC **48** may be coupled to the primary MECs **44** and secondary MECs **46** to provide backup power when the primary main AC power sources are not available to the primary power switching buses **96a** as explained in greater detail below.

Un-serviced equipment loads **50** in one or more zones occurs primarily for two reasons. Either all of the generators **34, 36** failed and therefore primary power is no longer available to any of the MECs **44, 46** or one or more of the buses **96** are physically damaged due to an event such as a rotor or tire burst. Rerouting of high voltage power from either of the four generators **34, 36** or auxiliary power unit generator **54** based on failure of one or more main primary power sources occurs at the primary bus level via the tie buses **76, 78, 80** through opening and closing of combinations of switches as shown by the primary power busing network system **90** depicted in FIG. 3. In one or more embodiments, one or more standalone solid state switches, for example contactors, are included on the primary power busing network system **90**. The solid state switches each have a self-contained control function configured to provide one or more of localized protections, voltage sensing, and current sensing, independent of the availability of other power system components. The standalone solid state switch can function without the need for data from other power system components. Opening and closing of the solid state switch interrupts and routes primary power across one or more of the primary power switching buses to one or more of the MECs **44, 46, 48**. Beginning with FIG. 3, specific contactors are depicted as either primarily closed or primarily open. The symbol for an open contactor is two parallel lines. The symbol for a normally closed contactor is the same with the exception that a diagonal line is drawn through the parallel lines. The standalone solid state switch may also include pulse width modulation to limit current flow through the standalone solid state switch. Rerouting of secondary power and low voltage DC between the MECs **44, 46, 48** based on failure of high voltage buses and conversion occur by the opening and closing of combinations of switches as shown by the power busing network system **90** as depicted in FIG. 3.

Each MEC **44, 46, 48** has both primary and secondary power and is capable of independently performing closed loop processing and local control of sensors without being dependent on a central computer system. The distributed power system control architecture permits sharing of the overall vehicle power distribution status among the MECs **44, 46, 48** but each MEC **44, 46, 48** is only responsible for servicing equipment loads **50** in proximity of each MEC, with the exception of MEC **48** which also distributes standby power to all other MECs **44, 46**. Each MEC **44, 46, 48** manages data associated with the zone of the nearest

equipment loads **50** such that each MEC **44, 46, 48** independently performs operations within its own zone of equipment loads **50**.

Each MEC **44, 46, 48** also preferably has solid state switching for bus power control and also provides circuit protections. In FIG. 3 power from primary power feeders **40, 42** connected to the generators **34, 36** energizes primary power switching buses **96a**. Each primary power switching bus **96a** branches off to a primary power switching bus **96b** within MEC **44** and a primary power switching bus **96c** within MEC **46**. Each primary power switching bus **96a** connected with distribution feed **98** to a primary power switching bus **96b** corresponds with a single primary MEC **44** as shown in FIG. 4 and as described in greater detail below.

Referring to FIG. 4, a portion of each primary MEC **44** with a primary power switching bus **96a** is a high power portion **120** and another portion of the primary MEC **44** with the primary power switching bus **96b** is a low power portion **122** of the primary MEC **44**. The high power portion **120** of a primary MEC **44** is configured to receive primary power from any high power main source available to the aircraft **10** and is sometimes referred to as a primary power switching network device **302**. The network of high power portions **120** of the primary MECs **44** within the aircraft **10** define a high voltage power busing network system.

The low power portion **122** is preferably configured to handle a fraction of the power from onboard power sources but still be able to handle the same voltages as the high power portions **120**. The primary power switching buses **96c** correspond with secondary MECs **46** shown in FIG. 4. FIG. 4 best illustrates the similarity between a secondary MEC **46** and the low power portion **122** of a primary MEC **44**. Primary MECs **44** include the primary level power network busing structure of primary power switching buses **96a** to reroute primary sources across the aircraft **10** that the secondary MECs **46** do not have. During normal as well as abnormal operations, the primary and secondary MECs **44, 46** both have primary and standby power. Secondary MECs **46** service the nearest equipment loads **50** just like a primary MEC **44**.

Referring back to FIG. 3, distribution feeds **98** extend between primary power switching buses **96a** and **96b** of each primary MEC **44** and distribution feeds **100** extend between each bus **96b** of the primary MEC **44** and the primary power switching bus **96c** of a secondary MEC **46** that directly receives power from the same source. Also, a crosstie **102** extends between the bus primary power switching **96b** of the primary MEC **44** associated with left generator **34a** and the primary power switching bus **96b** of the primary MEC **44** associated with the right generator **36a**. A crosstie **104** extends between the primary power switching bus **96c** of the secondary MEC **46** associated with left generator **34a** and the primary power switching bus **96c** of the secondary MEC **48** associated with the right generator **36a**. A crosstie **106** extends between the primary power switching bus **96b** of the primary MEC **44** associated with left generator **34b** and the primary power switching bus **96b** of the primary MEC **44** associated with the right generator **36b**. A crosstie **108** extends between the primary power switching bus **96b** of the secondary MEC **46** associated with generator **34b** and the primary power switching bus **96b** of the secondary MEC **46** associated with the right generator **36b**. Auxiliary power unit generator **54** is connected to the crossties **102, 106**, respectively.

FIG. 5A illustrates one configuration of the fault tolerant combined primary and secondary power distribution net-

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works of primary, secondary and standby MECS **44**, **46**, **48** within the aircraft **10**. For purposes of illustrating greater detail, FIGS. **5B-5E** illustrate close-up partial views of four separate portions which can be positioned next to each other to assemble the complete system depicted in FIG. **5A**. Two dot-dash lines on each of FIGS. **5B-5E** denote the broken edges of each partial view. FIG. **5B** illustrates the top left portion of FIG. **5A**. FIG. **5C** illustrates the top right portion of FIG. **5A**. FIG. **5D** illustrates the bottom left portion of FIG. **5A** and FIG. **5E** illustrates the bottom right portion of FIG. **5A**. Also, FIG. **5F** illustrates one configuration of the standby MEC **48** of the system of FIG. **5A**. The contactors shown in FIG. **3** are also shown symbolically in FIGS. **5A-5F**, but without reference numbers to simply FIGS. **5A-5F**, and may also be shown in other drawings without any reference numbers or having different reference numbers.

In FIG. **5A** the primary and secondary MECs **44**, **46** are arranged in such a way that there are a total of four in the forward sections of the aircraft **10** and another four in the aft sections of the aircraft **10**. Preferably, there is a primary MEC **44** and a secondary MEC **46** in each of a pair of forward sections and a primary MEC **44** and a secondary MEC **46** in each of a pair of aft sections. FIG. **5A** also shows a standby MEC **48** in an aft section of the aircraft **10**. The non-time limited power source for the standby MEC **48** can be a RAM air turbine (RAT) **128** or other suitable independent time limited standby power source such as a battery or fuel cell. In the event of an operational inconsistency with all the generators **34**, **36**, the RAT **128** is deployed to provide standby power to standby MEC **48** as well as to one or more of the MECs **44**, **46** in the event that all of the generators **34a**, **34b**, **36a**, **36b** have an operational inconsistency. The battery **598** provides temporary operational power to standby MEC **48** as well as to one or more of the MECs **44**, **46** while the non-time limited RAT **128** is being deployed.

If one of the generators **34a**, **34b**, **36a**, **36b** fails, power is not being received at the primary power switching bus **96a** of a primary MEC **46**. Therefore, the equipment loads **50** off of the lower power portion **122** of the primary power switching bus **96b** of the unpowered primary MEC **44** are unserved and the equipment loads **50** off of the primary power switching bus **96c** of an unpowered adjacent secondary MEC **46** are unserved. Power is then rerouted at the primary level from one of the other remaining operational sources by opening and closing of combinations of contactors to energize primary power switching bus **96a** of unpowered primary MEC **44** to power its equipment loads **50** and to energize primary power switching bus **96c** of any unpowered adjacent secondary MEC **46** to power its equipment loads **50**.

Alternatively, if a MEC **44**, **46**, **48** experiences a physical failure and as result its equipment loads **50** are unpowered, then power may be rerouted to power the equipment loads **50** of the unpowered MEC **44**, **46**, **48** by another powered MEC **44**, **46**, **48**. Depending on the amount of power available to be rerouted, all or only a portion of the equipment loads **50**, such as only the critical loads, may be repowered. Also, if all power sources are lost and the MECs **44**, **46**, **48** are unpowered, then the standby MEC **48** with the fuel cell or RAT **128** can power the critical equipment loads **50** of the other MECs **44**, **46**. Critical loads are those equipment loads **50** that the aircraft **10** must have powered to maintain continued safe flight and landing. Essential loads are those equipment loads **50** that are desirable to have such as radios and other communications equipment but operation is not required to fly the aircraft **10**. Non-essential loads

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are the lowest priority equipment loads **50** such as passenger comfort loads including food preparation devices, decorative lighting and cabin entertainment systems.

By way of example, the auxiliary power unit generator **54** could service the equipment loads **50** lost due to the failure of one of the main generators **34**, **36**. If generator **34b** fails then, through a combination of contactors in forward tie bus **76**, aft tie bus **78**, mid tie bus **80**, primary power is provided directly from the remaining main generators **34**, **36**. Alternatively, primary power may be provided from the auxiliary power unit generator **54** through another operational MEC **44**, **46** across one or more of the crossties **102**, **104**, **106**, **108**, to the primary power switching bus **96a** of an unpowered primary MEC **44** or to the primary power switching bus **96c** of an unpowered secondary MEC **46**.

In the event one or more of the MECs **44**, **46** has a physical operational inconsistency, all or part of the plurality equipment loads **50** within the zone associated with each operationally inconsistent MEC **44**, **46** can be associated with one or more other MECs **44**, **46** that are nearest in proximity. For example, if a primary MEC **44** physically fails, the equipment loads **50** once serviced by that failed MEC **44** may be serviced by another MEC **44**, **46** or a combination of MECs **44**, **46**. MECs **44**, **46** can determine the types of equipment loads **50** once serviced by the failed MEC **44** and then determine whether one or more of the combination of MECs **44**, **46** should service those unpowered equipment loads **50**. If it is determined that a secondary MEC **46** in closest proximity to the failed primary MEC **44** is to service the additional equipment loads **50** then the zone originally associated with that secondary MEC **46** is expanded to encompass the zone formerly serviced by failed primary MEC **44**.

Alternatively, the additional equipment loads **50** may be divided between a secondary MEC **46** and another primary MEC **46** in proximity to the failed primary MEC **46**. In such case, the zone of equipment loads **50** associated with the nearest operational primary MEC **44** is expanded to include a portion of the zone formerly serviced by failed primary MEC **44** and the zone of equipment loads **50** associated with the nearest operational secondary MEC **46** is expanded to include the remaining portion of the zone formerly serviced by failed primary MEC **44**. In either case, one or more other MECs **44**, **46** in proximity of a failed MEC **44**, **46** are sourced to independently provide the services to the equipment loads **50** previously serviced by the failed MEC **44**, **46**.

Each secondary MEC **46** and each low power portion **122** of each primary MEC **44** includes contactors coupled to conversion equipment. The conversion equipment includes a transformer rectifier unit (TRU) **134**, which rectifies the 230 VAC and converts it to the main DC output such as 28 VDC for bus **136**, and an autotransformer or auto-step down transformer unit (ATU) **138** to convert 230 VAC to 115 VAC for a low power AC output bus **140**. Each secondary MEC **44** and low power portion **122** of a primary MEC **44** further includes a second TRU **142**, not just for redundancy, but to provide power only to the critical loads absolutely necessary for continued safe flight and landing. Limiting the second TRU **142** to only critical loads ensures that the standby power sources are not overloaded.

FIG. **6** illustrates the configuration of a secondary power busing configuration, in forward section **12** for example, where the primary power switching buses **96b** in the low power portions **122** of the primary MECs **44** and the primary power switching buses **96c** of the secondary MECs **46** are tied together. As described above, whether all or only a portion of the unpowered equipment loads **50** of a damaged

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MEC 44, 46 are serviced by another MEC 44, 46 depends on available power. In the event one of the TRUs 134 in one of the MECs 44, 46 within an aircraft section fails, the most critical of equipment loads 50 from the operationally inconsistent TRU 134 may be serviced by another MEC 44, 46 in that same aircraft section providing secondary power across the various contactors and backup buses 148.

Preferably MECs 44, 46 in the aft section 16, have secondary power tie-ins from the auxiliary power unit generator 54 due to their proximity to one another which minimizes the power feeder wire weight. Also, the MECs 44, 46 in the forward section 12 of the aircraft 10 tie in at lower voltage levels such as 115 VAC from the external power ground service equipment such as external power unit 56 as shown in FIGS. 2 and 6. However, the 115 VAC from the ground to the low power AC output buses 140 in the MECs 48 in the forward section 12 could be converted to higher voltages such as 230 VAC by bi-directional ATUs 138 which then may be distributed to the other MECs 44, 46 in other sections of the aircraft 10. Also, a second TRU 142, typically used for more critical loads as explained above, allows battery power from battery bus 294 via backup bus 148 to power those critical loads that were lost.

As shown in FIG. 7, a computing (software and hardware) and network interface (CNI) module 162 located inside each MEC 44, 46, 48 provides distributed computing functions and gateway routing of bi-directional data. Each CNI module 162 contains two failsafe computing systems that become a fault tolerant computing system. Each fail safe computing system is redundant to the other. This fault tolerant computing system responds gracefully to unexpected hardware and/or software failures to allow no loss of service to system functions within the aircraft 10. The CNI module 162 transmits/receives data to/from internal MEC computing functions and external MEC computing functions via an internal system communication bus (such as Flex-Ray, Controller Area Network (CAN), ARINC 664, TTP or other bus technology). Other MECs 44, 46, 48 on the aircraft 10 will communicate with the CNI module 162 via a data networking specification, such as the ARINC 664, across external data communication channel A and external data communication channel B as shown in FIG. 7 having reference numbers 188 and 190, respectively.

The CNI module 162 is a distributed computing element that hosts specific software applications used within that localized zone of the aircraft 10. Some examples of the system applications that can be hosted on the CNI module 162 are the AC and DC power systems, cargo door system, passenger entry door system, landing gear system, and passenger cabin system. The computing functions that communicate to the CNI module 162 are TRUs 134, TRUs 142, ATUs 138, solid state switches of a breakers module 166, a generator control unit GCU 168 associated with one of the generator 34, 36, solid state power distribution modules 170, and remote data concentrators. The CNI module 162 communicates internally within the MEC 44, 46, 48 across internal data channel A 202 and internal data channel B 204 to the TRUs 134, 142, the ATUs 138, the breaker modules 166, the GCU 168, and the power distribution modules 170 as described in greater detail below.

The CNI module 162 will transmit and receive data to/from these computing functions. The CNI module 162 will also transmit and receive the status and health from other MECs 44, 46, 48 and aircraft computing systems. Each CNI module 162 manages the workload of an individual MEC 44, 46, 48 with knowledge of what is going on in other MECs 44, 46, 48. Once the information has been received by

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the CNI module 162 of a MEC 44, 46, 48, its computing function will determine which system needs the data, interpret the health of the data, respond to any power system anomalies, supply time sensitive information to computing functions that need it, perform system level logic algorithms, report airplane level system faults, and control the distribution of AC and DC power for that zone.

FIG. 8 illustrates the data network structure with communication bus interfaces between the spatially distributed MECs 44, 46, 48 separated by section breaks 18, 20, 22. This configuration allows each individual MEC 44, 46, 48 to communicate with other MECs 44, 46, 48 as well as provide the redundancy required to ensure continued communication across failures. Section break 20 defines forward and aft sections of the aircraft. The number of network communication switches needed is determined by the number of MECs 44, 46, 48 and the desired fault tolerance. FIG. 8 illustrates nine MECs 44, 46, 48 with three pairs of network switches 182a-b, 184a-b, 186a-b (hereinafter may be referred to collectively and/or generically as "network switches 182, 184, 186"). Each network switch 182, 184, 186 may be a multilayer network switch such as a layer-3 network switch that can receive secondary electrical power from the CNI modules 162 of each of the interfacing MECs 44, 46, 48. If there were more MECs 44, 46, 48 then more network switches would be required to achieve the same level of fault tolerance.

Each MEC 44, 46, 48 has A and B communication channels. Channels A and B of each primary MEC 44 connects to two corresponding A or B switches on either another primary MEC 44 or on a standby MEC 48. Each primary MEC 44 includes one switch 182, 184, 186 on either channel A or channel B, while standby MEC 48 in an aft section of the aircraft includes both switches of a pair of switches 182, 184, 186 on both A and B channels. Switches 182a, 184a, 186a correspond with channel A and switches 182b, 184b, 186b correspond with channel B. External communication data lines 192 indicate switch to switch data lines.

Generally, a network switch on each primary MEC 44 on one side of the section break 20 is connected to two other network switches of other primary or standby MECs 44, 48 where at least one of those MECs 44, 48 is on the other side of the section break 20 and one is on the opposite side of the aircraft 10. For example, network switch 182a of the forward right primary MEC 44 that is forward of the section break 20 is connected on the other side of the section break 20 to both network switch 184a on the aft left primary MEC 44 and to network switch 186a on the standby MEC 48. Network switch 182b on the forward left primary MEC 44 that is forward of the section break 20 is connected on the other side of the section break 20 to both network switch 184b on the aft right primary MEC 44 and to network switch 186b on the standby MEC 48. Network switch 186b on the standby MEC 48 is also connected to network switch 184b on the opposite side of the aircraft 10. Network switch 184a is also connected to network switch 186a of the standby MEC 48.

Each of the secondary MECs 46 also has two data channels with two other primary or standby MECs 44, 48. External communication data lines 196 indicate data connections of a network switch of a primary MEC 44 directly to a secondary MEC 44. One of the channels of each secondary MEC 48 is connected to a network switch on the same channel of a primary MEC 48 on the other side of the section break 20 and the other channel is connected to another secondary MEC 46. Therefore, FIG. 8 shows eight

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data bus connections crossing section break **20** and four data bus connections crossing each of the section breaks **18, 22**. This configuration minimizes the amount of communication wiring across section breaks as well as the overall weight of wiring in the aircraft. Separation is maintained between each data bus by utilizing the space in the crown and the floor of the aircraft **10**. Healthy CNI modules **162** can optimally respond to changing configurations of the power system in a coordinated fashion by utilizing local environment information and communications from other healthy CNI modules **162**.

If any two MECS **44, 46, 48** are powered then the communication network will be active and data will be present so that those two MECS **44, 46, 48** can fully communicate with each other. This communication network is a fault tolerant network in that any one connection between a pair of MECs may be lost without reducing any MEC **44, 46, 48** functionality. Moreover, loss of any two communication connections at the same time between the MECs **44, 46, 48** at most results in the loss of data communication with only one of the MECs **44, 46, 48**.

For example, loss of the network switch **182a** on channel A of the forward right primary MEC **44** does not result in complete loss of communications to and from the forward right primary MEC **44** because communications to and from forward right primary MEC **44** may continue through channel B. Any other MECs **44, 46, 48** which had communicated via channel A with the forward right primary MEC **44** can directly communicate through channel B or via other MECs **44, 46, 48** that are connected to forward right primary MEC **44** via channel B. Also, if network switch **182a** on channel A of the forward right primary MEC **44** was lost in addition to the channel B connection to the forward right secondary MEC **44**, communications to and from the forward right primary MEC **44** would continue via channel B but then communications would be lost only with the forward right secondary MEC **44** because both channels A and B were lost.

One aspect of the present disclosure is distributed power control architecture. Power control is distributed to each MEC **44, 46, 48** as well as power itself. Based on the local data each individual MEC **44, 46, 48** collects, each MEC **44, 46, 48** performs its own power control of its associated zone to configure its own equipment loads **50** without having to rely on any other MECs **44, 46, 48**. Only the data that is really necessary, such as the need to reroute power, is sent to the CNI modules **162** of other MECs **44, 46, 48**.

Normal power up of an aircraft **10** on the ground is preferably a sequential power up of the MECs **44, 46, 48**. Normal power up is done via the battery **598** which powers all the standby buses **160** in MECs **44, 46** via the static inverter **290** and the backup bus **148**. Should the battery **598** not be available, a limited amount of exterior power from the external power unit **56** is sent to power up the standby MEC **48**. Once the standby MEC **48** is powered up, power is then distributed from the standby MEC **48** to each of the other primary and secondary MECs **44, 46** to power up their CNI modules **162** and configure contactors within each MEC **44, 46** as appropriate with the power sources that are available. On the other hand, a sequential power up is not utilized if a MEC **44, 46** becomes unpowered during normal flight operations. If the CNI module **162** in one of the MECs **44, 46** has no primary power, the low power interconnection between two MECs **44, 46**, such as a primary MEC **44** and a secondary MEC **44** with a distribution feed **100**, provides a means to still power the unpowered MEC **44, 46** as explained above.

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The CNI module **162** reads input/output communications from other systems or LRUs as well as configuration data from other MECs **44, 46, 48**. Broadcasting each MEC's **44, 46, 48** configuration data allows each of the other MECs **44, 46, 48** to determine what is going on elsewhere in the aircraft **10**. The CNI module **162** then uses this data to configure breakers and contactors within its MEC **44, 46, 48** and then writes configuration data onto channel A or B about the equipment loads **50** within its zone to broadcast to the other MECs **44, 46, 48** so that other MECs **44, 46, 48** can do the same. Each CNI module **162** checks the validity of the communications input/output and environmental data it receives and, if necessary, refines it to determine its own environment data and states of its breakers. Once the CNI module **162** figures out how it wants to command its breakers and contactors within its zone, it then sends its configuration data out to the other MECs **44, 46, 48**.

The CNI module **162** of each MEC **44, 46, 48** only controls the equipment loads **50** within the boundaries assigned to that MEC **44, 46, 48**. Each CNI module **162** of a particular MEC **44, 46, 48** does not set the equipment load configuration of other MECs **44, 46, 48** or decide how to configure their breakers or contactors. However, all the MECs **44, 46, 48** still may interact with one another to provide a coherent and unified power transfer function for the primary and secondary power systems of the aircraft **10**. The CNI modules **162** of MECs **44, 46, 48** that are functioning properly are able to react to a MEC **44, 46, 48** that has operational issues and reroute power across power tie buses **76, 78, 80**, distribution feeds **98, 100** and crossties **102, 104, 106, 108** even in conjunction with additional failures. The computing and networking architecture is both fail safe and fault tolerant. If a CNI module **162** has an operational issue, all of its connected load will enter a predefined default "fail safe" state. Adjacent CNI modules **162** do not have the capacity or authority to control other equipment loads outside of their zone.

The CNI module **162** shown in FIG. 9 includes one network switch **182a, 184a, 186a** on one side of the CNI module **162** corresponding with channel A and another network switch **182b, 184b, 186b** on the other side corresponding with the channel B. Both network switches **182, 184, 186** have one or more ports **206** for making external data communication connections. Each side of the CNI module **162** also has one or more ports **208** for making internal data communication connections within the MEC **44, 46, 48** as described in greater detail below. The CNI module **162** includes two multi-core processors **242, 244** for running multiple instructions associated with processing channel A and channel B data communications. Each processor **242, 244** can process instructions for receiving and transmitting communication data within a MEC **44, 46, 48** at ports **208** or for receiving and transmitting communication data outside of the MEC **44, 46, 48** with either network switch **182, 184, 186** through the ports **206**. One of the processors **242, 244** on one side of the CNI module **162** corresponds with one communication channel and the other processor **244** on the other side of the CNI module **162** corresponds with the other communication channel. However, each processor **242, 244** has a crossover to the other network switch **182, 184, 186** for the other communication channel so that each processor **242, 244** can read and process both channel A and B communications.

Each component or LRU **52** placed on a truss system of a MEC **44, 46, 48** such as the CNI module **162** may include a barcode reader **248** for optically reading labels. The barcode reader **248** may be a quick response (QR) code

reader for reading QR codes. Barcodes (not shown) may be placed in the MEC, **44, 46, 48** or elsewhere in the aircraft **10** in proximity of the barcode reader **248**. The barcode reader **248** reading barcodes allows the MEC **44, 46, 48** to input information such as identification, position, time tracking and other configuration information to set software parameters of the CNI module **162** of the MEC **44, 46, 48**. For example, the barcode reader **248** may read the position of the CNI module **162** so that the MEC **44, 46, 48** knows which section or which side of the aircraft **10** it is located in. Also, determining the location of the CNI module **162** allows the MEC **44, 46, 48** to determine the nearest equipment loads **50**. The configuration information may also be transmitted to other MECs **44, 46, 48**, elsewhere in the aircraft **10**, or a central facility outside of the aircraft **10** such as a maintenance facility.

Based on how much power is distributed from the MEC **44, 46, 48**, the CNI module **162** may require one or more additional power inputs **288**, such as 28 VDC or 115 VAC, and power regulators **238**, from one or more transfer layers of a truss system as explained below. For example, 28 VDC is input to point of use regulator **280** for the barcode reader **248**. Each CNI module **162** also receives one or more DC power inputs **284** from power outputs **286** of the CNI modules **162** of one or more other MECs **44, 46, 48** to power one or both network switches **182, 184, 186**. Power inputs **284** and power regulators **246** provide redundancy to prevent a single power failure from taking down any of the processing or communication channels.

If there is a complete loss of power to a MEC **44, 46, 48** at inputs **288** from a transfer layer of the truss system, then the MEC **44, 46, 48** with the CNI module **162**, network switches **182, 184, 186**, the power regulators **246**, and the barcode reader **248**, may still be powered. Because of the one or more DC power inputs **284** routed from redundant power outputs **286** of other CNI modules **162** of other MECs **44, 46, 48**, the CNI module of the unpowered MEC **44, 46, 48** never loses power and is able to reroute power from an adjacent MEC and then powers up one or more transfer layers of its own MEC **44, 46, 48**. The MEC **44, 46, 48** can then still service some or all of its equipment loads **50** and the CNI module **162** remains fully functional and can communicate with other CNI modules **162** thereby keeping truss system of the MEC **44, 46, 48** and the communications network active.

A primary power switching network device (PPSND) **302** is shown in FIG. **10** with optional contactors **232, 250, 260, 278** for various loads based on the primary power switching configuration and where the MEC **44** is within an aircraft **10** as explained above. Each PPSND **302** corresponds with the high power portion **120** of each primary MEC **44** and is configured to share common sources and outputs with options for additional contactors **232, 250, 260, 278** for receiving primary power directly from a standby MEC **48** or for receiving primary power from auxiliary power unit generator **54** which are connected via the forward, aft and mid tie buses **76, 78, 80** as needed. As shown in FIG. **5C** the high power primary power switching bus **96a** of aft right primary MEC **44** is connected to the standby MEC **48** with tie **234**.

Each PPSND **302** includes a primary power connection **210** from one of the main generators **34, 36**, and a connection **212** to either the forward or aft ties **76, 78**. Each PPSND **302** also includes an output connection **214** to an associated secondary MEC **46**. Each PPSND **302** also includes two high current solid state contactors **216, 218** and two low current solid state contactors **220, 222**. The two high current

contactors **216, 218** are connected together at connection **224**. One of the high current contactors **216** is also connected at connection **210** for turning on and off main primary power and the other high current contactor **218** is also connected at the connection **212** for the forward or aft ties **76, 78** depending on whether the primary MEC **44** is in a forward or aft section of the aircraft **10**. The low current contactor **220** is connected to a connection **214** for the associated secondary MEC **46**. The other low current contactor **222**, in combination with the distribution feed **98** as described in greater detail below, is for turning on and off power between the high power portion **120** and the low power portion **122** of each primary MEC **44**. Each PPSND **302** may also include optional high current contactor **250**, a high current contactor **260**, a low current contactor **232**, or a low current contactor **278**. A set of substantially identical PPSNDs **302** can be used with a primary MEC **44** to receive three-phase primary power from one of the generators **34, 36**. Each of the primary power feeders **40, 42** preferably is a four conductor power wire connected to each of the primary MECs **44** where three of the conductors carry either of phases A, B or C of the three-phase power. The fourth conductor can be a neutral wire connected to a fourth PPSND. Sets of the solid state elements constitute the contactors **216, 218, 220, 222, 232, 250, 260** and **278** as depicted in FIG. **10**.

One or more of the MECs **44, 46, 48** may also include an integrated truss system having a mounting structure of one or more data and/or power transfer layers separated by one or more insulation layers. The truss is configured to facilitate easy installation or replacement within an aircraft **10** and may be constructed of rigid or flexible materials such as sheet metal, thermoplastics, composites, or some other suitable material. In an aircraft, power or data could be transferred to various locations on the mounting structure of the truss system or to various locations in the aircraft. In some configurations, a via or a mechanism such as a truss interconnect can electrically connect one or more power or data lines in one layer to one or more power or data lines in one or more different layers of the integrated truss system. The interconnect can also be used to electrically interconnect a LRU mounted to the top surface layer of the integrated truss system and to send power into the truss or from the truss into the LRU. An LRU with PPSNDs **302** has a conductive boss (projection) and as the interconnect passes through the LRU and into the truss system the interconnect expands into the boss as well as the transfer layers of the truss system to make electrical connections between the LRU and the truss system.

In some configurations, the integrated truss system may electrically connect both power and data systems. In further configurations, the truss interconnect can also provide a mechanical connection between one or more layers of the integrated truss system. In additional configurations, the truss interconnect may be configured for multiple insertions and extractions, allowing the reuse of the truss interconnect.

FIG. **11** illustrates an exploded, perspective view of a multi-layered integrated truss system **500** of a MEC **44, 46, 48**. The integrated truss system **500** may include insulation layers **502a-502b** (hereinafter referred to collectively and/or generically as “insulation layers **502**”) and transfer layers **504a-504c** (hereinafter referred to collectively and/or generically as “transfer layers **504**”). In some configurations, the insulation layers **502** and the transfer **504** layers are alternately arranged among each other such that the insulation layers at least partially electrically separate the transfer layers **504** from one another. In further configurations, the

insulation layers **502** are configured to, at least partially, physically separate one or more of the transfer layers **504** from one or more other transfer layers **504**. Also, in some configurations one or more of the insulation layers may act as a smoke or water drip barrier between the passenger and cargo compartments.

Components of a MEC **44, 46, 48** may be detachably secured to the truss system **500**. A portion of the power busing network system **90** of FIG. 3, for example corresponding with the high power portion **120** of a primary MEC **44**, with the PPSNDs **302**, is housed in an LRU **52** mounted to the top surface insulation layer **502a** of the truss system **500**. Also inside the LRU **52** with the power busing network system **90** is a microprocessor that receives channel A and B data inputs from the CNI module **162** to control all the contactors **216, 218, 220, 222, 232, 250, 260** and **278**.

Three-phase primary power **506a-d** (hereinafter may be referred to collectively and/or generically as “three-phase primary power **506**”) is provided from one of the main generators **34, 36** to the PPSNDs **302** inside the power busing network system **90**. Phase A power **506a**, phase B power **506b**, or phase C power **506c**, or all three, may be routed from the output connections **390a-c** through the insulation layers **502** to one or more transfer layers **504** of the truss system **500**. The neutral **506d** of the three phase primary power **506** also may be routed through the insulation layers **502** to one or more transfer layers **504** of the truss system **500**. Communication data is sent from one MEC **44, 46, 48** to any other MEC **44, 46, 48** across two data channels **188, 190** (commonly referred to as channels A and B). As shown in FIG. 11, the mounting structure of the truss system **500** provides separate layers configured to provide separate communication channels to system components mounted to the truss system **500**. Both data channels **188, 190** may be routed through the insulation layers **502** to one or more transfer layers **504** of the truss system **500**. For example, the transfer layer **504a** includes data transfer path **536** and transfer layer **504b** includes data transfer path **538**. The data transfer paths **536, 538** may be separated from one another by one or more layers **502, 504** such as transfer layer **504c**. Data communications back and forth between the power busing network system **90** with PPSNDs **302** and the CNI module **162** are sent back and forth across the data channels **188, 190**. Data channel **188** passes through the transfer path **536** of transfer layer **504a** and data channel **190** passes through the transfer path **538** of transfer layer **504c**.

In some configurations, the transfer layers **504** are configured to include one or more power or data transfer paths, or both. For example, the transfer layer **504b** may include power transfer paths **512a** and **512b** which correspond with phase B power **506b** and neutral **506d** of the three phase primary power **506**. The power transfer path **512a** receives phase B power, of 230 VAC for example, and transfers it to another LRU **52** mounted to the truss system **500** such as the CNI module **162** shown in FIG. 11. Transfer path **512b** is the current return path across the neutral **506d** from the CNI module **162** back to one of the PPSNDs **302**.

Each MEC **44, 46, 48** also includes at least one power distribution module **170** for distributing secondary power from the MECs **44, 46, 48**. Each distribution module **170** may be configured as one or more LRUs **52**. Each distribution module **170** preferably receives all three phases but distributes them to single phase leads in a balanced manner. As shown in FIG. 11, phase A power **506a** and phase B power **506b** are provided through two different transfer layers **504** of the truss system **500**. Also, phase A power **506a** and phase B power **506b** would be distributed to

distribution modes **170**. Each distribution module **170** then distributes single phase secondary power to the low power equipment loads **50** within the assigned zone of each particular MEC **44, 46, 48**. The equipment loads **50** associated with each MEC **44, 46, 48** are preferably distributed evenly across all three power phases. Preferably, each of the low power equipment loads **50** is connected to a distribution module **170** with a twisted electrical conductor pair. Although the present application depicts a particular number of connections in one or more of the Figures, any number of equipment loads **50** may be serviced by a MEC **44, 46, 48** subject to the amount of secondary power available.

Communication data from channels A and B **202, 204** of truss transfer layers **504a, 504b** controls when a distribution module **170** turns on and off secondary power to the twisted and shielded electrical conductor pairs to service the equipment loads **50**. The CNI module **162** is connected to every trace in every layer **504** of the truss system **500** of a MEC **44, 46, 48**. Because there are multiple voltage inputs to the CNI module **162**, power regulators perform conversions to the needed voltages. If any of the traces on one or more of the layers **504** become powered, the CNI module **162** becomes active. For example, if all the MECs **44, 46** loses primary power, power could be provided to the standby MEC **48** with the RAT **128** or a fuel cell thereby providing power to traces within a standby layer of the truss system. Power in the traces would activate the CNI module **162**. The CNI module **162** also receives communication data for use with the network switches **182, 184, 186** from both channels A and B **202, 204** from each of the transfer paths **536, 538** of the transfer layers **504a, 504b**.

FIG. 12 also generally illustrates the distribution of either AC or DC power from an ATU **138** or a TRU **134**, respectively. However, more specifically as described above, the primary power **506** is first distributed to the power conversion equipment and then to the distribution modules **170** connected to each of the low power equipment loads **50** with multiple twisted and shielded electrical conductors where the conductors carry essentially equal but opposite currents. In application there may be small differences in current carried by the conductors. For example, twisted and shielded electrical conductor pair **314** includes an electrical power conductor **310** and a neutral or return conductor **312**. The neutral conductor may be routed with a three-phase power feeder.

After converting the primary power **506**, AC power is distributed from each ATU **138** to AC equipment loads **50a** with an electrical power conductor **310** and current is returned from each AC equipment load **50a** on a corresponding return conductor **312** of the twisted and shielded electrical conductor pair **314**. DC power is provided from each TRU **134** to the DC equipment loads **50b** with electrical power conductor **310**. Current is returned from each DC equipment load **50b** on the corresponding return conductor **312** of the twisted electrical conductor pair.

Phase A power **506a**, phase B power **506b**, and phase C power **506c** are distributed from the generators **34, 36**. A fourth wire from the generators **34, 36** for the three-phase primary power **506** is also depicted that is the neutral conductor **506d**. Each of the AC equipment loads **50a** includes a shield termination wire **590** depicted by a broken line connected to the neutral conductor **506d** and each of the DC equipment loads **50b** includes a shield termination wire **592** also depicted by a broken line connected to the neutral conductor **506d**. Although each of the equipment loads **50a** and **50b** are connected to the neutral conductor **506d** with shield termination wires **590** and **592**, respectively, the load

return currents are no longer cumulative. In FIG. 12, part of the neutral conductor **506d** is configured to appear as a current return network (CRN) merely to illustrate that the voltage differential is zero as a result of using small loops of twisted wire conductor pairs for localized secondary power distribution. The neutral conductor **506d** of the distributed three-phase primary power **506** between MECs **44**, **46**, **48** of the aircraft **10**, which is much smaller than conductors that would typically be utilized as part of a CRN, may simply be referred to as a safety ground bus (SGB). Therefore, a CRN is no longer needed in the composite aircraft **10** with localized secondary power distribution provided by twisted wire conductor pairs. The twisted wire conductor pair now provides current return. Also, the cross-sectional area of the loops created by the twisted conductor pair is much smaller than the cross-sectional area created by the larger wire loop of the CRN which reduces the lighting threat to the composite aircraft **10**. For comparison, the conductors of the twisted pair may be about 16 to about 20 American wire gauge (AWG) whereas the conductors of the CRN are about 2 AWG or larger diameter.

FIG. 12 also illustrates the distribution of primary power from generators **34**, **36** among primary MECs **44** distributed within the forward, mid and aft sections of the aircraft **10**. Each primary MEC **44** includes a TRU **134** and an ATU **138** for servicing equipment loads **50b** and equipment loads **50a**, respectively, as described above. Power is distributed from each MEC **44** to each equipment load **50** with a twisted and shielded electrical conductor pair **314**. FIG. 12 also depicts a pair of MECs **44** providing 230 VAC for auxiliary loads **520**. As referenced in FIGS. 12A-12C and the accompanying text, 230 VAC power to and from the auxiliary loads is controlled by the contactors **232**, **278** of the PPSNDs **302** of the primary MEC **44**.

FIG. 12 also illustrates a plurality of LRUs **52**, such as avionics, serviced by the forward most primary MEC **44**. FIG. 12 also illustrates a battery **598** for providing standby power. Although FIG. 12 depicts the battery **598** providing standby power to only the forward most primary MEC **44**, battery standby power is preferably provided to all primary MECs **44**.

FIG. 13 illustrates an integrated truss system **600** which may be used in aircraft manufacturing for providing one or more power and data transfer paths as explained above. One or more MECs **44**, **46**, **48** may include the truss system **600** as a support or mounting structure for attaching all or part of vehicle systems, components of a MEC **44**, **46**, **48**, equipment loads **50**, LRUs **52**, or other equipment.

The mounting structure of the truss system **600** may be a multi-part or modular assembly of separate structural elements that stack, detachably connect or lock together to create an integrated mounting structure that may be installed in an aircraft **10** as a single unitary piece. Each structural element may have one or more transfer layers and one or more insulation layers as described above. Each structural element of the multi-part truss system **600** may be detachable from one another to allow repair or replacement of damaged structural elements without removing undamaged structural elements from the aircraft **10**. One or more layers of each structural element may also be replaced. One element of the truss system **600** could be swapped out without having to remove the entire truss system **600**. Also, all or at least a portion of the truss system **600** may also be detachable from the support structure of the aircraft **10** such as the floor beams or fuselage frame members. Alternatively, the truss system **600** may be manufactured as a single monolithic structure which may be installed or replaced in it's

entirely. The truss system **600** is configured to extend within a thin structural volume defined in the sidewall of the fuselage between frame members, and by the depth of the frame members, or in the space in the floor between the passenger and cargo compartments of the aircraft **10**, and by the depth of the floor beams. Alternately, a truss such as truss system **600** could have a physical form configured to be implemented within a traditional equipment bay. The truss system **600** mounted in the sidewall of the aircraft **10** preferably corresponds with the curvature of the fuselage of the aircraft **10**. FIG. 13 is a bottom view looking upward toward the truss system **600** configured to extend from sidewall to sidewall of the aircraft **10**, under seat rails **610**, and between transverse floor beams **608**. A MEC **44**, **46**, **48** positioned in the floor or in the sidewall of the aircraft **10** with a truss system such as truss system **600** can service the equipment loads **50** within the passenger compartment and in the cargo compartment of the aircraft **10** that are in proximity of the MEC **44**, **46**, **48**.

The truss system **600** is configured to have a narrow middle portion that extends over the top of two inner adjacent floor beams **608** and opposite end portions that extend further outward from both sides of the two inner adjacent floor beam **608** to the next floor beams **608** to provide a wide surface for mounting components such as the power distribution modules **170**. In one or more embodiments, the truss system is configured to have a width and length between adjacent floor beams **608**, or between floor beams **608** that are displaced from one another, that is suitable for serving as a smoke barrier for obstructing smoke from the cargo compartment from entering the passenger compartment and/or as a water drip barrier for obstructing water from the passenger compartment from dripping into the cargo compartment.

FIG. 13 also shows the CNI module **162**, power distribution modules **170**, TRUs **134**, **142**, the ATU **138**, and the PPSNDs **302** mounted to the truss system **600** of a primary MEC **44**. The TRU **134** receives 230 VAC from the output connections **390** of the PPSNDs **302**. The TRUs **134** connect to a power bus with 28 VDC to power the distribution modules **170**. Each power distribution module **170** has connections **596** for interfacing with the equipment loads **50** associated with the primary MEC **44**.

Each structural element of the truss system **600** has one or more transfer and insulation layers as explained above. One of the transfer layers may be configured to transfer high voltage power from one portion of a MEC **44**, **46**, **48** to another portion of that same MEC **44**, **46**, **48**. For example, high voltage power may be provided inside the truss system **600** across a transfer layer to the PPSNDs **302**, configured as an LRU **52**, mounted to the surface of truss system **600**. Low voltage secondary power may also be provided through another transfer layer of the truss system **600** to low power equipment loads **50** mounted to the surface of the truss system **600**. Also, communication data can be provided across a transfer layer of the truss **600** to an aircraft system component mounted to the surface of the truss system **600**. One transfer layer of the truss system **600** could provide channel A to a system component mounted to the surface of the truss system **600** and another transfer layer could provide channel B to that same system.

One or more configurations of the aircraft **10** may include one or more remote modular equipment centers (RMECs) **410** configured for use with power and data elements in specific environments of the aircraft **10**. An RMEC **410** is a simpler version of a primary or secondary MEC **44**, **46** that does not have power conversion equipment such as TRUs

134, 142, or the ATU 138. Any of the MECs 44, 46, 48 can source an RMEC 410 with secondary power. One or more discrete secondary power inputs are provided to the RMEC 410, from one or more power distribution modules 170 of the nearest primary or secondary MEC 44, 46, at a specific voltage for a load associated with that RMEC 410. AC power could also be provided to the RMEC 410 directly from a PPSND 302, if required for a load of a local subsystem.

Each RMEC 410 distributes secondary power and communication for providing localized power and performing computing functions specifically for the local equipment and components of the aircraft system in proximity of the RMEC 410. Because RMECs 410 distribute discrete secondary power and do not include power conversion equipment, the amount of wiring is reduced between the local sensors and components and the MECs 44, 46. This reduces overall aircraft wire weight and wire complexity throughout the aircraft 10 which expedites assembly of the aircraft 10. Also, build verification is simplified and final assembly of the aircraft is expedited because the RMEC 410 may be packaged together with devices, configured to provide data and receive commands and power from the RMEC 410, into a unitary system, such as a passenger entry door system or a main landing gear system, that can be production qualified prior to or immediately after installation within the aircraft 10.

RMECs 410 may be used in the pressurized areas as well as the unpressurized areas of the aircraft 10. RMECs 410 can route communications from outside a pressurized portion of the aircraft to a pressurized portion of the aircraft. For example, RMECs 410 may be used in the nose and main wheel well areas with the landing gear system, nose wheel steering system, brake system, and hydraulic systems. RMECs 410 may also be used in the passenger entry and cargo door areas with the door indication system, flight look system, emergency power, and the forward or aft cargo door systems. RMECs 410 could also be used in the wing and engine areas with the engine data concentrator system and the wing flap and slat system. Other areas where RMECs 410 may be used are the cabin areas for the lavatory, galley, lighting, and passenger seat power systems. RMECs 410 may be used in the flight deck areas with panel components and window heat system and the cargo compartment areas with the forward and aft cargo handling systems. RMECs 410 may also be used in the environmental control and cooling systems.

As shown in FIG. 14 one or more configurations of the aircraft 10 includes an RMEC 410 with each of the passenger entry door systems 404, with the forward cargo door system 406 and the aft cargo door system 408, a pair of RMECs 410 for the two nose wheel systems, a pair of RMECs 410 for the two main wheel well systems, an RMEC 410 for the panel in the cockpit, RMECs 410 for the left and right main engine data concentrators, RMECs for the left and right wing slats, and RMECs 410 for the left and right wing flaps.

FIG. 15 illustrates a block diagram of RMEC 410 having a fault-tolerant power and communication system 412. The RMEC 410 is customizable based upon the needs of an aircraft subsystem in proximity of the RMEC 410. All the electrical circuits along with the power into the RMEC 410 may be housed in a LRU 52. Sensors and other components of a particular local subsystem then interface with the LRU 52 of the RMEC 410 to prevent numerous penetrations of wire bundles back into the pressurized vessel of the aircraft 10. The wires associated with any sensors or components of

the local subsystem are kept in proximity of the RMEC 410 by directly interfacing with the RMEC 410 rather than penetrate back into the pressurized vessels of the aircraft 10. Preferably, there is no direct power or data path between the devices on the exterior of the pressurized vessel and within the zone of an associated RMEC 410 to a MEC 44, 46, 48. A concentrator configured to combine data from multiple sources in an associated zone of an RMEC 410 onto a single path may be used to minimize the size of the penetration into a pressurized portion of the aircraft 10. For example, only A and B data channels 188, 190 and two twisted and shielded electrical conductor pairs 314 penetrate a pressurized portion of the aircraft 10 to provide bi-directional communication and secondary power to the RMEC 410. The RMEC 410 routes communications from outside a pressurized portion of the aircraft 10 to a pressurized portion of the aircraft 10. The RMEC 410 interfaces with either a primary MEC 44 or a secondary MEC 46 for secondary DC power distributed by two twisted and shielded electrical conductor pairs 314 connected to the same or different distribution modules 170 of the same primary or secondary MEC 44, 46.

Channel A and B communication data from the CNI module 162 of the MEC 44, 46 is received at communication bus electronic circuits 414, 416 and the two twisted and shielded electrical conductor pairs 314 provide 28 VDC or 115 VAC to power supply circuits 418, 420. Channel A and B multi-core microcontroller electronic circuits 422, 424 with non-volatile memory 428 receive and process communication data for digitally controlling the sensors and other components interfaced with other electronic circuits within the RMEC 410. If one of the microcontrollers 422, 424 has an operational inconsistency, the other of the microcontrollers 422, 424 takes over with no loss of function or data.

Whether the communications from the RMECs 410 are time sensitive may determine whether an RMEC 410 communicates with a primary MEC 44 or a secondary MEC 46. If the communications associated with the equipment loads of an RMEC 410 are time sensitive then it is preferable that the RMEC 410 communicates the time sensitive communication data to a primary MEC 44. If the communications from an RMEC 410 are not time sensitive then the RMEC 410 can communicate the non-critical communication data to a secondary MEC 46. Therefore, time sensitive communication data from one or more of the RMECs may be routed to the primary MEC and other than time sensitive communication data from one or more RMECs may be routed to the secondary MEC. An example of a time sensitive communication is whether the landing gear is up within a period of time for obstacle clearance at the end of a short runway. An example of communications that are not time sensitive is when passenger conveniences have failed. The communications between a MEC 44, 46 to the RMEC 410 can be accomplished either by CAN, ARINC 664, Ethernet, Flex-Ray or some other bus architecture.

Electronic circuits that may also be included in one or more configurations of the RMEC 410 are proximity sensor electronic circuits 432 for interfacing with proximity sensors 434, discrete input switch electronic circuits 436 for interfacing with discrete switches 438, temperature sensor electronic circuits 440 for interfacing with temperature sensors 442, and variable differential transformer electronic circuits 444 interfacing with variable differential transformers (VDT) 446 for determining positions of devices such as motors of the local subsystem.

FIG. 15 also illustrates one or more power distribution electrical circuits 450 of the remote MEC 410 for providing DC or AC power to loads 50, solenoids 454, relays 456,

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switches **458**, lights **460**, or squibs **462**. However, the use and number of loads **50**, solenoids **454**, relays **456**, switches **458**, lights **460**, or squibs **462** depends on the configuration and location of the subsystem for each remote MEC **410**. To complete the circuits, the remote MEC **410** also includes one or more discrete output switch electrical circuits **452** for providing grounded return path outputs. All the wiring for the loads **50**, solenoids **454**, relays **456**, switches **458**, lights **460**, or squibs **462** is local to the RMEC **410**.

FIGS. **16A** and **16B** illustrate a block diagram of one or more configurations for a RMEC **410** for a main landing gear control and indication system. The RMEC **410** and the main landing gear system interfacing with the RMEC **410** are positioned outside the pressurized vessel of the aircraft **10**. The RMEC **410** of FIGS. **16A** and **16B** includes the fault-tolerant power and communication system **412** with redundant communication and power channels as well as proximity sensor electrical circuits **432**. Solenoids **454** on the right side of the MEC **410** interface with one or more solid state power control and indication electrical circuits (SSPCs) **466** and one or more ground/open analog discrete output control and indication electrical circuits **468**. Both the SSPC **466** and the ground/open analog discrete output control and indication electrical circuit **468** receive a power input **470**, for example 28 VDC from a power distribution module **170** of a MEC **44**, **46**, to supply power through switches **472** to the solenoids **454**. When the logic of the switches **472** is correct both power and ground is supplied to the solenoids **454** to open and close the landing gear door and enable, tilt, raise up and down the land gear. One or more hydraulic pressure transducer electronic circuits **474** for monitoring a hydraulic pressure transducer **476** may also be included for indicating when hydraulic lines of the landing gear system are pressurized. A program jumper pin electronic circuit **478** of the RMEC **410** changes the configuration of the aircraft subsystem by adding or removing jumpers.

FIGS. **17A** and **17B** illustrate a block diagram of one or more configurations for a RMEC **410** for use on a passenger entry door of a passenger entry door system **404**. The RMEC **410** and the passenger entry door system **404** interfacing with the RMEC **410** are positioned inside the pressurized vessel of the aircraft **10**. The RMEC **410** of FIGS. **17A** and **17B** also includes the fault-tolerant power and communication system **412** with redundant communication and power channels as well as proximity sensor electrical circuits **432**. Proximity sensors **434** indicate the state of the position of the passenger entry door system **404**.

Proximity sensors **434** and proximity sensor electronic circuits **432** on the left side of the MEC **410** interface with one or more control panel discrete output electronic circuits **480** with a passenger entry door control panel **482** for indicating when the passenger entry door is closed, latched, and locked, one or more flight lock actuator discrete output electronic circuits **484** with a flight lock actuator **486**, one or more pressure transducer discrete input/output electronic circuits **488** with a pneumatic reservoir **490** having excitation, sensing, power and ground lines and a hydraulic pressure transducer **476**, and one or more discrete input electronic circuits for a passenger entry door switch **494**. All the wiring for the passenger entry door **482**, flight lock actuator **486**, pneumatic reservoir **490** and the passenger entry door switch **494** is within the passenger entry door system **404** and local to the RMEC **410**.

Turning now to FIG. **18**, an illustrative routine **700** for providing power and data to remote power and data elements of a vehicle is provided. Unless otherwise indicated,

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more or fewer operations may be performed than shown in the figures and described herein. Additionally, unless otherwise indicated, these operations may also be performed in a different order than those described herein.

The routine **700** starts at operation **702**, where one or more power sources generate primary power. Operation **704** includes distributing primary power to the MECs **44**, **46**, **48**. In operation **706** each MEC **44**, **46**, **48** services equipment loads **50** with secondary power. In operation **708** at least one MEC **44**, **46**, **48** distributes secondary power to an RMEC **410**. Operation **710** includes associating the RMEC **410** with one or more power and data elements. In operation **712**, each RMEC **410** distributes secondary power to the one or more power and data elements.

FIGS. **19-22** and the following discussion are intended to provide a general description of a computing environment **810** capable of implementing aspects of the embodiments presented herein. It should be understood that the scope of the computing environment **810** changes as building of the aircraft **10** progresses and therefore depends on the state of the build of the aircraft **10**. Moreover, FIGS. **19-22** are simplified representations of the computer environment **810** for purposes of explanation and ease of description, and FIG. **19-22** are not intended to limit the application or scope of the subject matter described herein in any way.

Each of FIGS. **19-22** depict a block diagram of an illustrative computer hardware and software architecture for the computer environment **810**. It should also be appreciated that the computer environment **810** of FIGS. **19-22** may be implemented on computing devices onboard one or more of the partially constructed vehicle portions or a completely assembled aircraft **10**. It should also be appreciated that the computer environment **810** of FIGS. **19-22** may be further implemented by one or more computing devices within one or more vehicle manufacturing and/or assembly facilities. In some configurations, the computer environment **810** may be implemented by computing devices of the combination of one or more facilities having one or more partially constructed vehicle portions or a fully assembled aircraft **10** therein.

The computer environment **810** can be defined by the state of the vehicle build. FIG. **19** illustrates one embodiment wherein the computer environment **810** encompasses one or more computing devices within a facility that has completed installation of at least one equipment system within one or more partially constructed vehicle portions. A partially constructed vehicle portion may be any portion of a vehicle that is used in an assembly process that forms part of an assembled vehicle, such as the aircraft **10**, and that requires installation of one or more equipment systems. For example, a partially constructed vehicle portion may be part of the fuselage of the aircraft **10** such as all or part of one of the sections **12**, **14**, **16**. Also, a partially constructed vehicle portion can include, but is not limited to, one or more MECs **44**, **46**, **48**, wherein power is distributed across all or part of the power busing network system **90** to equipment loads **50**. In another embodiment, a partially constructed vehicle portion may be an RMEC **410** utilized within all or part of a passenger entry door system **404**, cargo door system **406**, **408**, landing gear system, a nose wheel steering system, a brake system, hydraulic systems, or the like.

As the building of the aircraft **10** progresses, the scope of the computer environment **810** varies depending on the current build stage of the partially constructed vehicle portions due to the installation of equipment systems. In one or more embodiments, such as when the aircraft is fully assembled and flight ready as shown in FIG. **22**, the com-

puter environment **810** only includes the computing devices within the aircraft **10** such as, but not limited to, the flight management system (FMS) **840**, maintenance system **842**, communication system, navigation system, and avionics systems **844** that are installed on the aircraft **10**. The computer environment **810** of FIG. **22** no longer includes the computing devices within the facilities for tracking and managing the manufacturing and assembly process once assembly of the aircraft **10** is completed.

One or more configurations of the computer environment **810** includes a build verifications system **812**. In an exemplary embodiment, the build verification system **812** includes build verification software and is configured to perform the tasks, functions, and operations described below. The various tasks may be performed by software, hardware, firmware, or any combination thereof. It should be appreciated that any number of additional or alternative tasks may be included, and may be incorporated into a more comprehensive procedure or process having additional functionality not described in detail herein.

The build verification system **812** can be used to verify that equipment systems when installed are electrically connected properly within one or more partially constructed vehicle portions. The build verification system **812** may be implemented by software embedded on a combination of computing devices, e.g., a plurality of processing cores, a combination of a digital signal processor and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a digital signal processor core, or any other such configuration. The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in firmware, in a software module executed by any practical combination of computing devices.

While software may be described in the general context of program modules that execute in conjunction with one or more application programs that run on an operating system on one or more computing devices such as a computer, those skilled in the art will recognize that the invention may be implemented in combination with one or more other modules. Generally, software providing the logic or control for various operations and functions of this disclosure includes program modules that can include routines, programs, components, data structures, and other types of structures that perform particular tasks or implement particular abstract data types. Moreover, those skilled in the art will appreciate that aspects of this disclosure may be practiced with various computer system configurations, including hand-held devices, multiprocessor systems, microprocessor-based or programmable consumer electronics, minicomputers, mainframe computers, and the like. Aspects of the disclosure may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

Software may be categorized into multiple criticality levels based on safety related conditions, events or circumstances that could lead to or contribute to an unplanned or undesirable event associated with vehicles such as the aircraft **10**. Level A software is software whose behavior would cause or contribute to a failure resulting in a catastrophic failure condition for the aircraft **10**. A catastrophic failure results in whole loss of the aircraft **10** or loss of life. Level B software is software whose behavior would cause or contribute to a failure resulting in a hazardous failure condition for the aircraft. A hazardous failure results in

major damage to the aircraft that is repairable or results in injuries. Level C software is software whose behavior would cause or contribute to a failure resulting in a major failure condition for the aircraft. Level D software is software whose behavior would cause or contribute to a failure resulting in a minor failure condition for the aircraft. Level E software is software whose behavior would cause or contribute to a failure of a system function with no effect on aircraft operational capability or pilot workload.

In one or more configurations, software necessary for operating a vehicle when completely assembled, such software for flying away the aircraft **10** and operating the aircraft **10** during flight, has a first level of criticality and whereas the build verification software has a second level of criticality for when the vehicle such as the aircraft **10** is being manufactured and assembled. In such case, the first level of criticality is higher level than the second level of criticality. For example, flight management software associated with the FMS **840** is level A software. Lower level software associated with the build verification system **812** or the factory build system **816** does not have to meet flight criticality that would allow the aircraft to fly away and therefore could be level E software. Software for systems such as communication and navigation systems and other avionics systems could be either level B, C or D software. In FIGS. **19-22**, the higher criticality level software such as software associated with the FMS **840** is designated by reference number **834** and the lower criticality level software such software of the build verification system **812** or the factory build system **816** is designated by reference number **832**.

The aircraft **10** has many types of electronic equipment systems on board. A particular electronic equipment system on the aircraft **10** in the form of one or more LRUs **52** may use software or programming to provide the logic or control for various operations and functions. One or more LRUs **52** may include, for example, without limitation, the build verification system **812**, the FMS **840**, the CNI module **162**, an autopilot, an in-flight entertainment system, a communications system, a navigation system, a flight controller, a flight recorder, an engine monitoring unit, and a collision avoidance system.

In FIG. **19** the computer environment **810** includes one configuration of the build verification system **812** where one or more partially constructed vehicle portions include all or part of the power busing network system **90**. FIG. **19** depicts an RMEC **410** as a portion of the power busing network system **90** with the fault-tolerant power and communication system **412** of the RMEC **410** interfacing with one or more sensors **814** located on the one or more partially constructed vehicle portions. Although FIGS. **19-22** depict sensors **814**, in practice the sensors **814** could correspond to one or more of the equipment loads **50**, proximity sensors **434**, discrete switches **438**, temperature sensors **442**, VDTs **446**, solenoids **454**, relays **456**, switches **458**, lights **460**, or squibs **462**, as described above in association with an RMEC **410**.

The fault-tolerant power and communication system **412** of the RMEC **410** also interfaces with factory build system **816**. The factory build system **816** includes the administrative software such as factory build software on one or a combination of computing devices within one or more facilities for scheduling and tracking the vehicle build as well as coordinate the inventory needed for partially constructed vehicle portion or aircraft **10**. In one or more embodiments, the factory build system **816** may also include an external computer **820** (FIG. **26**) operative to access one or more of the MECs **44, 46, 48**, RMECs **410**, or some other

computing device operative to host and execute the build verification software. The build verification software may also be hosted and executed from a removable storage device. The computer **820** communicatively interfaces with a database management system **822** having the online work instructions (OWIs) **824**. As shown in FIG. **19**, the computer **820** communicatively interfaces with the RMEC **410** with a data link and/or communication system.

The computer **820** is capable of executing the software in the manner presented above and may be embodied in single computing device or in a combination of one or more processing units, storage units, and/or other computing devices implemented in the FMS **840** and/or other avionics system **844** of the aircraft **10**. The computer **820** includes one or more central processing units **972** ("CPUs"), a system memory **974**, including a random access memory **976** ("RAM") and a read-only memory **978** ("ROM"), and a system bus **980** that couples the memory to the CPUs **972**.

The CPUs **972** may be standard programmable processors that perform arithmetic and logical operations for the operation of the computer **920**. The CPUs **972** may perform the operations by transitioning from one discrete, physical state to the next through the manipulation of switching elements that differentiate between and change these states. Switching elements may generally include electronic circuits that maintain one of two binary states, such as flip-flops, and electronic circuits that provide an output state based on the logical combination of the states of one or more other switching elements, such as logic gates. These basic switching elements may be combined to create more complex logic circuits, including registers, adders-subtractors, arithmetic logic units, floating-point units, and the like.

The computer **820** also includes a mass storage device **982**. The mass storage device **982** may be connected to the CPUs **972** through a mass storage controller (not shown) further connected to the bus **980**. The mass storage device **982** and its associated computer-readable media provide non-volatile storage for the computer **820**. The mass storage device **982** may store various software modules and components of the FMS **840** and/or other avionics systems **844**, as well as specific application modules or other program modules. The mass storage device **982** may also store data collected or utilized by the various systems and modules.

The computer **820** may store programs and data on the mass storage device **982** by transforming the physical state of the mass storage device **982** to reflect the information being stored. The specific transformation of physical state may depend on various factors, in different implementations of this disclosure. Examples of such factors may include, but are not limited to, the technology used to implement the mass storage device **982**, whether the mass storage device **982** is characterized as primary or secondary storage, and the like. For example, the computer system **820** may store information to the mass storage device **982** by issuing instructions through the storage controller to alter the magnetic characteristics of a particular location within a magnetic disk drive device, the reflective or refractive characteristics of a particular location in an optical storage device, or the electrical characteristics of a particular capacitor, transistor, or other discrete component in a solid-state storage device. Other transformations of physical media are possible without departing from the scope and spirit of the present description, with the foregoing examples provided only to facilitate this description. The computer system **820** may further read information from the mass storage device

982 by detecting the physical states or characteristics of one or more particular locations within the mass storage device **982**.

Although the description of computer-readable media contained herein refers to a mass storage device, such as a hard disk or CD-ROM drive, it should be appreciated by those skilled in the art that computer-readable media can be any available computer storage media that can be accessed by the computer **820**. Computer-readable media includes communication media, such as transitory signals, and computer-readable storage media. Computer-readable storage media includes volatile and non-volatile, removable and non-removable media implemented in any method or technology for the non-transitory storage of information such as computer-readable instructions, data structures, program modules, or other data. For example, computer-readable storage media includes, but is not limited to, RAM, ROM, EPROM, EEPROM, flash memory or other solid state memory technology, CD-ROM, digital versatile disks ("DVD"), HD-DVD, BLU-RAY, or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store the desired information in a non-transitory fashion and that can be accessed by the computer **820**.

According to various embodiments, the computer **820** may operate in a networked environment using logical connections through a network, such as the network **984**, or to other avionics systems **844** in the aircraft **10**. The computer **820** may connect to the network **984** through a network interface unit **986** connected to the bus **980**. It should be appreciated that the network interface unit **986** may also be utilized to connect to other types of networks and remote computer systems such those with a facility for manufacturing and assembling the aircraft **10**. The computer **820** may also include an input-output controller **988** for receiving input and providing output to displays, such as the aircraft display unit **990**, or to aircraft terminals.

In one or more configurations, depending on the current state of the build of portions of the aircraft **10**, build verification system **812** capability may be included on one or more of the MECs **44**, **46**, **48**, in combination with one or more RMECs **410**. FIG. **20** illustrates an RMEC **410** along with a MEC **44**, **46**, **48** installed in one or more partially constructed vehicle portions and operative to access one another. FIG. **21** illustrates multiple MECs **44**, **46**, **48** installed in one or more partially constructed vehicle portions and operative to access one another. The build verification system **812** includes software hosted on the CNI modules **162** of the MECs **44**, **46**, **48** and hosted on the RMECs **410**. As referenced above, the build verifications system **812** may also be hosted and executed by the external computer **820**.

In an exemplary embodiment, the CNI modules **162** of the MECs **44**, **46**, **48** and fault-tolerant power and communication system **412** of the RMECs **410** generally represents hardware, software, and/or firmware components configured to facilitate communications and/or interaction with the build verification system **812** to perform tasks and/or functions to support testing of installed equipment systems. The CNI modules **162** with processors **242**, **244** and the fault-tolerant power and communication system **412** of the RMECs **410**, or any other hosting device, include processing logic that may be configured to carry out the functions, techniques, and processing tasks associated with the operation of the build verification system **812**.

The computer **820** may be used as a user input device. The CNI modules **162** with processors **242**, **244** and the fault-tolerant power and communication system **412** are cooperatively configured to allow a user to interact with the build verification system **812**. For example, the user may define test objectives to be performed by the build verification software based on the one or more installed equipment systems and on the one or more prerequisite equipment systems that are not yet installed during a current build stage. Thus, testing is preferably performed only on the one or more installed equipment systems that were installed during the current build stage according to the test objectives. However, testing is typically performed in a chronological progression of steps. If a step or test cannot be performed because equipment is not yet present or installed equipment has failed, subsequent steps are put on hold until resolved. Through emulation, tests on equipment not yet installed or failed tests can be skipped and other testing can continue. Testing on the equipment that is not yet installed or tests that have failed can be performed later out of sequence. Also, the tests are intended to be performed throughout the build process, during final assembly, and up until just before full power-on of the completely assembled aircraft **10**. The distributed nature of the build verification system **812** allows partially constructed vehicle portions to be tested separately or in combination with one another prior to the aircraft being completely assembled and flown away. Once the tests are satisfactorily completed, the aircraft receives full power, undergoes final checkout, and is then delivered to the buyer.

The build verification system **812** may also be coupled to the FMS **840**. The FMS **840** generally represents the hardware, software, and/or firmware components configured to control operations of the aircraft **10** during flight. The FMS **840** may access or include one or more databases suitably configured to support flight operations of the aircraft **10** such as, for example, the navigation system, the communications system **112**, and one or more additional avionics systems **844** to support navigation, flight planning, and other aircraft control functions, as well as to provide real-time data and/or information regarding the operational status of the aircraft **10** during flight.

Although FIGS. **19-22** each depict a single avionics system **844** in practice, the aircraft **10** could include any number of avionics systems for obtaining and/or providing real-time flight-related information that may be displayed or otherwise provided to a user. For example, a practical embodiment of the aircraft **10** would likely include one or more of the following avionics systems suitably configured to support operation of the aircraft **10**: a weather system, an air traffic management system, a radar system, a traffic avoidance system, an autopilot system, an auto-thrust system, a flight control system, hydraulics systems, pneumatics systems, environmental systems, electrical systems, engine systems, trim systems, lighting systems, crew alerting systems, electronic checklist systems, an electronic flight bag and/or another suitable avionics system.

The factory build system **816** within each manufacturing and assembly facility includes a predetermined build plan for assembling the aircraft **10**. The build plan is the coordinated and systematic arrangement of inventory at one or more locations to facilitate and track the progress of assembling a vehicle such as the aircraft **10**. The build plan may instead be implemented by one or more other software modules elsewhere in the computer environment **810**. The build plan includes multiple distinguishable build stages, typically in chronological order, where all the tasks within a

particular build stage are completed before moving on to the next build stage for assembling the aircraft **10**.

The build verification system **812** may include or have access to the factory build system **816** and one or more databases for determining which equipment systems are required to be installed during each build stage. The build verification system **812** may determine, track, or otherwise identify a current build stage from the factory build system **816** and the current progress of the build plan for assembling the aircraft **10**. The build verification system **812** can determine from the factory build system **816** which equipment systems are prerequisites for completing each build stage. Once the current build stage is known, the prerequisite equipment systems to be installed during the current build stage in the one or more partially constructed vehicle portions may be determined by the build verification system **812** from the factory build system **816**. The build verification system **812** may also determine from the factory build system **816** which prerequisite equipment systems are not yet installed according to the current build stage.

In one or more configurations, the determination of the current build stage can be made through an interrogation of completed and open OWIs or the current build stage can be input to the build verification system **812** by an operator interfacing with the factory build system **816** such as when signing off on OWIs **824** according to the build plan. Thus, the build verification system **812** can determine which OWIs **824** have been completed and which have not from the factory build system **816** to determine which prerequisite equipment systems have been installed during the current build stage, as well as during any previous build stage, as well as which equipment systems have not yet been installed during the current build stage. Each of the prerequisite equipment systems, when installed in the one or more partially constructed vehicle portions during the current build stage, may be referred to as an installed equipment system.

Electrical connections of each of the installed equipment systems, that were designated for installation during the current build stage, are also tested during the current build stage to determine whether the installed equipment systems are electrically connected correctly in the partially constructed vehicle portion. In addition to testing electrical connections, there may also be testing of data connections. The data connection of an installed equipment system may be tested to determine whether data communications exist to the installed equipment system in the partially constructed vehicle portion.

Upon the determination by the build verification system **812** that one or more prerequisite equipment systems have not yet been installed according to the current build stage, then the build verification system **812** may ignore testing of prerequisite equipment systems that are to be installed during the current build stage but are not yet present in the partially constructed vehicle portion or emulate testing of the prerequisite equipment systems that are to be installed during the current build stage but are not yet present in the partially constructed vehicle portion. In such case, the build verification system **812** eliminates or suppresses nuisance errors in the testing as a result of prerequisite equipment systems not yet installed within the one or more partially constructed vehicle portions.

The tests performed by the build verification system **812** with the build verification software may be invoked automatically by the build verification software of the build verification system **812** upon the CNI module **162** of a MEC **44**, **46**, **48**, or the fault-tolerant power and communication

system **412** of an RMEC **410**, or some other hosting device within the build verification system **812**, upon receiving data from across communication data lines **192**. For example, a CNI module **162** or the fault-tolerant power and communication system **412** of an RMEC **410**, may receive contactor information regarding the state of various contactors as explained below.

Testing functions may include Electrical Wiring Interconnection System (EWIS) testing such as, but not limited to, reflectometry methods, differential detection, voltage or current sensing, overcurrent, temperature sensing, for verifying wiring integrity and accurate fault location and isolation. These techniques may characterize wire length and if a wire connection is open or shorted. Specific test functionality may be customized at each location and integrated with electrical protective functions. If a failure is detected during a test, the installed equipment system may be isolated from other installed equipment systems within the one or more partially constructed vehicle portions until the installed equipment system generating the failing test data is repaired or replaced.

As part of one or more tests to be conducted on installed equipment systems during the current build stage, the build verification system **812** may emulate the functions of one or more prerequisite equipment systems (such as prerequisite equipment systems to be installed later in the current build stage or in a subsequent build stage) that are not yet present in the partially constructed vehicle portion or not yet present in some other portion of the aircraft **10** such as another partially constructed vehicle portion that is not in proximity to or connected to the partially constructed vehicle portion having the installed equipment systems being tested. For example, software of the build verification system **812** may emulate one or more functions performed by the FMS **840** that is not yet installed while testing the partially constructed vehicle portion. Also, the build verification system **812** may emulate the opening and closing of one or more contactors that are to be used in combination with prerequisite equipment systems that are not yet installed. For example, the build verification system **812** may emulate data communications that include the state of at least one contactor of the primary power switching network device **302**, or one or more other contactors within the power busing network system **90**, that is not yet present in the partially constructed vehicle portion during the current build stage.

The build verification system **812** could also emulate data communications from prerequisite equipment systems not yet present during the current build stage. For example, the build verification system **812** could emulate data communications for controlling primary power across the power busing network system **90** for distribution of primary power that is not yet fully installed. For example, primary power may not yet be available to a MEC **44**, **46**, **48** in the partially constructed vehicle portion because the power busing network system **90** may not yet have one or more other MECs **44**, **46**, **48** with PPSNDs **302** and therefore may not yet be completed. In another example, the build verification system **812** may emulate one or more other MECs **44**, **46**, **48** that are not yet present to test a MEC **44**, **46**, **48** installed in the one or more partially constructed vehicle portions as if the one or more other MECs **44**, **46**, **48** were present. In particular, wherein a partially constructed vehicle portion includes an installed first MEC having a first plurality of contactors, a second MEC having a second plurality of contactors could be emulated for the first MEC to test collecting of contactor information of the second plurality of contactors at the CNI module **162** of the first MEC.

Upon determining that there are no prerequisite equipment systems left to be installed during the current build stage, testing of all installed equipment systems that were installed according to the current build stage, and determining that all installed equipment systems are correctly installed, then the installation of equipment systems may proceed to a subsequent one of the build stages. Also, because some equipment systems are installed on top of other equipment systems making them difficult to access and repair, while the aircraft **10** is still being assembled, the build verification system **812** may also test whether earlier installed equipment systems, that were installed during one or more earlier build stages according to the build plan, remains correctly installed during a subsequent build stage. The build verification system **812** may test during the current build stage whether the installed equipment systems installed during a previous build stage remain correctly electrically connected within the partially constructed vehicle portion. In other words, the build verification system **812** may progressively test during subsequent one or more build stages whether the installed equipment systems remain correctly electrically connected or it had been accidentally disturbed.

The build verification system **812** may also determine from the factory build system **816** or from input from the operator which installed equipment systems are safe to operate while someone is in proximity to the partially constructed vehicle portion. In such case, the build verification system **812** could automatically test only the installed equipment systems that are safe to operate when in proximity to someone. In one or more configurations, for the equipment systems which are unsafe to operate when someone is close by, for example raising and lowering of landing gear, the build verification system **812** may require input from an operator that it is safe to proceed with testing of any installed equipment systems that could hazardous and result in personal injury. In one or more other configurations, the build verification system **812** may configure one or more contactors to provide protection and power at a first power level when one or more installed equipment systems are designed for a second power level and wherein the first power level is lower than the second power level. For example, tests could be performed at the lower power level so that the installed equipment systems are not damaged or so that personnel working on the partially constructed vehicle portion are not harmed. The contactors have preset protection ratings but lower test voltages could be sent to ensure everything is operating correctly. The preset protections could be scaled down to less than one amp, if desired, and be supersensitive in the event there is a misconnection or a fault. Then after testing and it is determined that everything is connected properly, it would be possible to revert back to the normal preset protections. In one or more configurations, the build verification system **812** may also configure one or more contactors to have a first protection sensitivity to limit damage when originally designed with a second protection sensitivity. The first protection sensitivity is lower than the second protection sensitivity. Thus, varying the power and protection sensitivity by gradually scaling up or increasing power and the protection ratings to normal operating levels could provide a safety feature to limit the extent of damage in the event of an improper connection.

The build verification system **812** may generate a record of each occurrence of one or more tests that are performed on each of the installed equipment systems. The record may also include the parameters under which the test was performed such as, but not limited to, the results of the test,

number of times the test was performed, the current build stage, other installed equipment with the partially constructed vehicle portion, the prerequisite equipment that was not yet installed, and which prerequisite systems were emulated and how they were emulated in order to perform the test. The record may be stored within the build verification system **812** until the aircraft **10** is fully assembled or in the factory build system **816** for any period of time including after the aircraft **10** is fully assembled.

The build verification system **812** is preferably partitioned from the FMS **840** and is disabled or removed once the aircraft **10** is fully assembled. In one configuration, the FMS **840** is installed in the aircraft **10** in place of the software for the build verification system **812** after final assembly of the aircraft **10**. Thus, as shown in FIG. **22**, the build verification system **812** may be removed from the aircraft **10** and the computer environment is limited to the computing devices and systems within a flight ready aircraft **10**.

FIG. **23** illustrates one configuration of the build verification system **812** interfacing with the CNI modules **162** of three primary MECs **44** as part of the power busing network system **90**. However, the aspects of the disclosure disclosed by FIG. **23** are not limited to any particular number of primary MECs **44**. For a limited power-on for testing a completely assembled aircraft **10** or one or more partially constructed vehicle portions having one or more primary MECs **44**, low voltage test power may be applied at the external power input which is then routed to the contactors **94**, **216**, **218**, **220**, **222**, **250**, **260**. However, for a full power-on, temporary test computing power may be applied to power up each of the CNI modules **162**. The CNI module **162** interfaces with the contactors **94**, **216**, **218**, **220**, **222**, **250**, **260** of the MECs **44** to determine contactor information from each of the contactors **94**, **216**, **218**, **220**, **222**, **250**, **260**. The CNI modules **162** include contactor configuration logic and the control for configuring the contactors **94**, **216**, **218**, **220**, **222**, **250**, **260**.

In each MEC **44** of FIG. **23** a solid arrow labeled "Contactor Inform." is pointing toward the CNI module **162** to depict the contactor information being sent back to the CNI modules **162**. The contactor information includes the state of the contactors **94**, **216**, **218**, **220**, **222**, **250**, **260** such as whether they are present, open or closed, and if there is voltage present. There are also other solid arrows to depict contractor control from each CNI module **162** to the contactors **94**, **216**, **218**, **220**, **222**, **250**, **260** of each MEC **44** and the contactor voltage from the contactors **94**, **216**, **218**, **220**, **222**, **250**, **260** to the CNI modules **162**. The low voltage test power sensed at each contactor input and output is compared. The CNI modules **162** sense that a particular contactor is open when there is no voltage present at the contactor output. On the other hand, the CNI modules **162** senses that a contactor is closed when there is voltage present at the contactor output.

Each MEC **44** includes an internal MEC data network among the particular contactors **94**, **216**, **218**, **220**, **222**, **250**, **260** present within each MEC **44**. The internal MEC data network is shown in each MEC **44** of FIG. **23** by a dotted line between the CNI module **162** and the particular contactors **94**, **216**, **218**, **220**, **222**, **250**, **260** of each MEC **44**. The CNI module **162** of each MEC **44** receives contactor information from each of its contactors and therefore knows the state of each of its contactors through the internal MEC data network. Also, as explained above, the switches **182**, **184**, **186** of each CNI module **162** of each MEC **44** are connected via external communication data lines **192** to switches **182**, **184**, **186** of the CNI modules **162** of the other

MECs **44**, **46**, **48**. Therefore, contactor information can be broadcast across the data network of the one or more partially constructed vehicle portions to share the contactor information among the MECs **44**, **46**, **48** in order to configure the power busing network system **90**, described above. Each MEC **44**, **46**, **48** may subscribe to the data network for the contactor information it needs.

To prevent damage to the aircraft **10** in the event of a fault, the low voltage test power is not itself enough to power up the CNI modules **162**. If there are no operational inconsistencies using a low voltage test power and test computing power, the CNI modules **162** may be powered up through its own truss system with one or more DC power inputs **284**, as shown in FIG. **9**, which in turn powers the network switches **182**, **184**, **186**. Also, DC power is output from power outputs **286** of the CNI module **162** to power other CNI modules **162**.

Preferably, the low voltage test power is sequentially routed throughout the power busing network system **90**. For example, the low voltage test power may be applied to one MEC **44**, **46**, **48** at a time until all the MECs **44**, **46**, **48** within one or more partially constructed vehicle portions are successfully tested or the aircraft **10** is completely assembled. In FIG. **23**, when the contactor **94** is closed, it can be determined whether the low voltage test power is present at one or more of the other contactors **216**, **218**, **220**, **222** of the left MEC **44** via the internal MEC data network. Closing the contactor **218** of the left MEC **44** then allows the low voltage test power to proceed to the middle MEC **44** which then may also be tested. The low voltage test power may also then proceed to the right MEC **44** shown in FIG. **23** in a similar manner. The testing of the contactors in such a manner within the MECs **44**, **46**, **48** and elsewhere within of the power busing network system **90** may be referred to as a peer-to-peer test sequence. The peer-to-peer test sequence may be performed after each of the one or more equipment systems are installed in one or more partially constructed vehicle portions until the aircraft **10** is fully assembled. FIG. **23** also illustrates the computer **820** for initiating the testing of the build verification system **812**, for monitoring the power busing network system **90**, and to verify the functionality and the responses of the installed equipment systems. The computer **820** reads the data such as the contactor information that is broadcast across the communication data lines **192**.

As explained above, the build verification system **812** may also be hosted on a RMECs **410**, having the fault-tolerant power and communication system **412** with the multi-core microcontroller electronic circuits **422**, **424**, wherein the RMEC **410** is an installed equipment system within a partially constructed vehicle portion. Testing electrical connections as well as testing data connections between a MEC **44**, **46**, **48** and an RMEC **410** can be performed with the build verification software application. For example, in FIG. **16B**, the SSPC **466** or the ground/open analog discrete output control and indication electrical circuit **468** of the RMEC **410** command one or more switches **472** closed to energize one or more corresponding solenoids **454**. When the switches **472** are closed the SSPC **466**, or the ground/open analog discrete output control and indication electrical circuit **468** will have information about whether current is flowing and about the voltages as well. Therefore, the SSPC **466** or the ground/open analog discrete output control and indication electrical circuit **468** monitor data made available as a result of sensing current and voltages to determine if there is a completed circuit. The SSPC **466**, and the ground/open analog discrete output control and indica-

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tion electrical circuit **468** share the data with the fault-tolerant power and communication system **412** as shown by the two-way arrows in FIG. **16B**.

FIG. **24** illustrates a computer-implemented routine **900** for verifying proper installation of equipment systems in a vehicle designed to be assembled in multiple build stages. Unless otherwise indicated, more or fewer operations may be performed than shown in the figures and described herein. Additionally, unless otherwise indicated, these operations may also be performed in a different order than those described herein. The routine **900** may start at operation **902**, where one or more partially constructed vehicle portions of the vehicle are provided. Operation **904** includes providing a build plan for assembling the vehicle comprising a plurality of build stages and operation **906** includes providing build verification software. At operation **908** the build verification software determines from the build plan a current build stage of the partially constructed vehicle portion. The build verification software at operation **910** includes determining one or more prerequisite equipment systems to be installed in the one or more partially constructed vehicle portions according to the current build stage. Operation **912** includes determining which of the one or more prerequisite systems have been installed in the one or more partially constructed vehicle portions during the current build stage, thereby defining one or more installed equipment systems. Operation **914** includes emulation of not yet installed prerequisite equipment systems necessary for one or more tests. Operation **916** then includes testing during the current build stage whether the one or more installed equipment systems are electrically connected correctly in the one or more partially constructed vehicle portions.

FIG. **25** illustrates a computer-implemented routine **950** for verifying proper installation of equipment systems of a primary power bus network within a first MEC. Unless otherwise indicated, more or fewer operations may be performed than shown in the figures and described herein. Additionally, unless otherwise indicated, these operations may also be performed in a different order than those described herein. The routine **950** starts at operation **960**. Operation **960** includes routing a low voltage test power to a first plurality of contactors within the first MEC. Operation **962** includes determining whether or not the low voltage test power is present at each of the first plurality of contactors of the first MEC. Operation **964** includes collecting contactor information from each of the first plurality of contactors across an internal MEC data network of the first MEC to a CNI module of the first MEC. The routine **950** may also include operation **966** routing the low voltage test power to a second plurality of contactors in a second MEC.

It will be further appreciated that the computer **820** may not include all of the components shown in FIG. **26**, may include other components that are not explicitly shown in FIG. **26**, or may utilize an architecture completely different than that shown in FIG. **26**. According to one or more embodiments, the computer **820** may have access to computer-readable storage media storing computer-executable instructions that, when executed by the computer, perform the routines **900**, **950**, as described above in regard to FIGS. **24** and **25**.

One or more embodiments may include a computer-readable storage medium with instructions for determining a current build stage of one or more partially constructed vehicle portions from a plurality of build stages, instructions for determining prerequisite equipment systems to be installed in the one or more partially constructed vehicle portions during the current build stage, instructions for

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determining which prerequisite equipment systems are to be installed during the current build stage that are not yet installed in the one or more partially constructed vehicle portions, and instructions for testing during each of the plurality of build stages whether at least one installed equipment system installed in the partially constructed vehicle portion is properly electrically connected within the one or more partially constructed vehicle portions. The computer readable storage medium may also include instructions for emulating missing prerequisite equipment systems necessary for one or more tests.

One or more embodiments may include a computer comprising a processor and a computer-readable storage medium in communication with the processor. The computer-readable storage medium includes computer-executable instructions stored thereupon that, when executed by the processor, cause the processor to determine a current build stage of one or more partially constructed vehicle portions from a plurality of build stages; determine prerequisite equipment systems to be installed in the one or more partially constructed vehicle portions during the current build stage; determine which prerequisite equipment systems are to be installed during the current build stage that are not yet present in the one or more partially constructed vehicle portions; and test during each of the plurality of build stages whether at least one installed equipment system installed in the partially constructed vehicle portion is properly electrically connected within the one or more partially constructed vehicle portions. The processor could also execute instructions for emulating missing prerequisite equipment systems necessary for one or more tests.

The subject matter described above is provided by way of illustration only and should not be construed as limiting. Various modifications and changes may be made to the subject matter described herein without following the example embodiments and applications illustrated and described, and without departing from the true spirit and scope of the present disclosure, which is set forth in the following claims.

What is claimed is:

1. A computer-implemented method for verifying proper installation of equipment systems in a vehicle designed to be assembled in multiple build stages, the method comprising:
 - retrieving a data structure describing a build plan for assembling the vehicle, wherein the build plan comprises a plurality of build stages, and wherein the build plan specifies, for each of the plurality of build stages, a respective plurality of prerequisite equipment systems to be installed in the vehicle during the build stage;
 - determining a current build stage, of the plurality of build stages, of one or more partially constructed vehicle portions of the vehicle;
 - determining a set of prerequisite equipment systems to be installed in the one or more partially constructed vehicle portions, corresponding to the current build stage;
 - determining one or more equipment systems that have been installed in the one or more partially constructed vehicle portions during the current build stage, based on build state information for the one or more partially constructed vehicle portions;
 - determining one or more diagnostic tests that are configured to test for a predefined electrical connectivity of the one or more equipment systems;
 - emulating, by operation of one or more non-transitory computer processors, data communications, over a data

communications network, from one or more prerequisite equipment systems not yet installed in the one or more partially constructed vehicle portions, during the current build stage;

initiating the one or more diagnostic tests, during the current build stage, using the emulated data communications from the one or more prerequisite equipment systems, to determine whether the one or more equipment systems are correctly installed in the vehicle, without requiring the one or more prerequisite equipment systems to be physically installed in the one or more partially constructed vehicle portions; and

upon determining that the one or more systems are incorrectly installed, based on a failure of a first one of the one or more diagnostic tests, facilitating a correction of the failure of the first diagnostic test.

2. The computer-implemented method of claim 1, further comprising testing during the current build stage whether data communications exist to the one or more installed equipment systems in the one or more partially constructed vehicle portions.

3. The computer-implemented method of claim 1, further comprising determining during the current build stage which prerequisite equipment systems are not yet installed.

4. The computer-implemented method of claim 3, further comprising ignoring testing of prerequisite equipment systems to be installed during the current build stage, but not yet installed in the one or more partially constructed vehicle portions.

5. The computer-implemented method of claim 1, further comprising suppressing nuisance errors as a result of prerequisite equipment systems not yet installed within the one or more partially constructed vehicle portions.

6. The computer-implemented method of claim 1 further comprising testing whether the one or more installed equipment systems correctly installed during the current build stage remain correctly installed during a subsequent one of the plurality of build stages.

7. The computer-implemented method of claim 1, wherein emulating data communications comprises emulating data communications for controlling distribution of primary power across a power busing network system that is not yet available to the one or more partially constructed vehicle portions during the current build stage.

8. The computer-implemented method of claim 7, wherein emulating data communications comprises indicating a state of at least one contactor of a primary power switching network device that is not yet installed in the one or more partially constructed vehicle portions during the current build stage.

9. The computer-implemented method of claim 1, further comprising determining which installed equipment systems are safe to operate while someone is in proximity to the one or more partially constructed vehicle portions, and automating the testing of at least one of the one or more installed equipment systems on the one or more partially constructed vehicle portions.

10. The computer-implemented method of claim 1 further comprising generating a record of each occurrence of one or more tests performed during one or more of the plurality of build stages on the one or more installed equipment systems on the one or more partially constructed vehicle portions.

11. The computer-implemented method of claim 1, further comprising progressively testing during subsequent one or more of the plurality of build stages whether the one or more

installed equipment systems remain correctly electrically connected to the one or more partially constructed vehicle portions.

12. The computer-implemented method of claim 1, further comprising testing during the current build stage whether the one or more installed equipment systems installed during a previous build stage remain correctly electrically connected to the one or more partially constructed vehicle portions.

13. The computer-implemented method of claim 1, further comprising partitioning build verification software from flight management software.

14. The computer-implemented method of claim 1, further comprising disabling build verification software after final assembly of the vehicle.

15. The computer-implemented method of claim 1, further comprising removing build verification software after final assembly of the vehicle.

16. The computer-implemented method of claim 1, further comprising installing flight management software in place of build verification software after final assembly of the vehicle.

17. The computer-implemented method of claim 1, further comprising hosting build verification software on a computing and network interface (CNI) module of a modular equipment center (MEC) in the one or more partially constructed vehicle portions.

18. The computer-implemented method of claim 17, testing electrical connections between one or more equipment loads and the MEC in the one or more partially constructed vehicle portions.

19. The computer-implemented method of claim 17, testing data connections between one or more equipment loads and the MEC in the one or more partially constructed vehicle portions.

20. The computer-implemented method of claim 1, further comprising hosting build verification software on a computing and network interface (CNI) module of a modular equipment center (MEC) and on a CNI module of a remote modular equipment center (RMEC), and testing an electrical connection between the MEC and the RMEC.

21. The computer-implemented method of claim 20, further comprising testing a data connection between the MEC and the RMEC.

22. The computer-implemented method of claim 1, further comprising hosting build verification software on a computing and network interface (CNI) module of a remote modular equipment center (RMEC) in the one or more partially constructed vehicle portions.

23. The computer-implemented method of claim 22, testing electrical connections between one or more sensors and the RMEC in the one or more partially constructed vehicle portions.

24. The computer-implemented method of claim 22, testing data connections between one or more sensors and the RMEC in the one or more partially constructed vehicle portions.

25. The computer-implemented method of claim 1, further comprising hosting build verification software on a removable storage device.

26. The computer-implemented method of claim 1, further comprising defining test objectives to be performed by build verification software based on the one or more installed equipment systems and the one or more prerequisite equipment systems not yet installed during the current build stage, and testing only the one or more installed

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equipment systems installed during the current build stage according to the test objectives.

27. The computer-implemented method of claim 1, further comprising determining there are no prerequisite equipment systems left to be installed during the current build stage, testing all installed equipment systems according to the current build stage, determining all installed equipment systems are correctly installed, and proceeding to a subsequent one of the plurality of build stages.

28. The computer-implemented method of claim 1, further comprising hosting build verification software on a computing and network interface (CNI) module of a modular equipment center (MEC) installed in the one or more partially constructed vehicle portions, and the build verification software emulating one or more other MECs that are not yet installed to test the MEC in the one or more partially constructed vehicle portions as if the one or more other MECs were present.

29. The computer-implemented method of claim 1, further comprising emulating opening and closing of one or more contactors used in combination with one or more prerequisite equipment systems that are not yet installed.

30. The computer-implemented method of claim 1, further comprising emulating flight management software that is not yet installed.

31. The computer-implemented method of claim 1, further comprising configuring one or more contactors to provide power at a first power level when one or more installed equipment systems are designed for a second power level, wherein the first power level is lower than the second power level.

32. The computer-implemented method of claim 31, further configuring one or more contactors to have a first protection sensitivity when designed with a second protection sensitivity, wherein the first protection sensitivity is lower than the second protection sensitivity.

33. A system, comprising:

one or more computer processors; and

a non-transitory memory containing computer program code that, when executed by operation of the one or more computer processors, performs an operation for verifying proper installation of equipment systems in a vehicle designed to be assembled in multiple build stages, the operation comprising:

retrieving a data structure describing a build plan for assembling the vehicle, wherein the build plan comprises a plurality of build stages, and wherein the build plan specifies, for each of the plurality of build stages, a respective plurality of prerequisite equipment systems to be installed in the vehicle during the build stage;

determining a current build stage, of the plurality of build stages, of one or more partially constructed vehicle portions of the vehicle;

determining a set of prerequisite equipment systems to be installed in the one or more partially constructed vehicle portions, corresponding to the current build stage;

determining one or more equipment systems that have been installed in the one or more partially constructed vehicle portions during the current build stage, based on build state information for the one or more partially constructed vehicle portions;

determining one or more diagnostic tests that are configured to test for a predefined electrical connectivity of the one or more equipment systems;

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emulating data communications, over a data communications network, from one or more prerequisite equipment systems not yet installed in the one or more partially constructed vehicle portions, during the current build stage;

initiating the one or more diagnostic tests, during the current build stage, using the emulated data communications from the one or more prerequisite equipment systems, to determine whether the one or more equipment systems are correctly installed in the vehicle, without requiring the one or more prerequisite equipment systems to be physically installed in the one or more partially constructed vehicle portions; and

upon determining that the one or more systems are incorrectly installed, based on a failure of a first one of the one or more diagnostic tests, facilitating a correction of the failure of the first diagnostic test.

34. The system of claim 33, further configured to test during the current build stage whether data communications exist to the one or more installed equipment systems.

35. The system of claim 33, further comprising software having a first level of criticality for operating the vehicle when completely assembled and wherein the build verification software has a second level of criticality, and wherein the first level of criticality is higher level than the second level of criticality.

36. A non-transitory computer-readable storage medium containing computer program code that, when executed by operation of one or more computer processors, performs an operation comprising:

retrieving a data structure describing a build plan for assembling the vehicle, wherein the build plan comprises a plurality of build stages, and wherein the build plan specifies, for each of the plurality of build stages, a respective plurality of prerequisite systems to be installed in the vehicle during the build stage;

determining a current build stage, of the plurality of build stages, of one or more partially constructed vehicle portions of the vehicle;

determining a set of prerequisite equipment systems to be installed in the one or more partially constructed vehicle portions, corresponding to the current build stage;

determining one or more equipment systems that have been installed in the one or more partially constructed vehicle portions during the current build stage, based on build state information for the one or more partially constructed vehicle portions;

determining one or more diagnostic tests that are configured to test for a predefined electrical connectivity of the one or more equipment systems;

emulating, by operation of one or more non-transitory computer processors, data communications, over a data communications network, from one or more prerequisite equipment systems not yet installed in the one or more partially constructed vehicle portions, during the current build stage;

initiating the one or more diagnostic tests, during the current build stage, using the emulated data communications of the one or more prerequisite equipment systems, to determine whether the one or more equipment systems are correctly installed in the vehicle, without requiring the one or more prerequisite equipment systems to be physically installed in the one or more partially constructed vehicle portions; and

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upon determining that the one or more systems are incorrectly installed, based on a failure of a first one of the one or more diagnostic tests, facilitating a correction of the failure of the first diagnostic test.

37. The non-transitory computer-readable storage medium of claim 36, further comprising ignoring testing of prerequisite equipment systems to be installed during the current build stage, but not yet present in the one or more partially constructed vehicle portions.

38. The non-transitory computer-readable storage medium of claim 36, further comprising suppressing nuisance errors as a result of prerequisite equipment systems not yet installed within the one or more partially constructed vehicle portions.

39. The non-transitory computer-readable storage medium of claim 36, further comprising testing whether the one or more installed equipment systems correctly installed during the current build stage remain correctly installed during a subsequent one of the plurality of build stages.

40. The non-transitory computer-readable storage medium of claim 36, further comprising emulating data communications across a power busing network system for distribution of primary power that is not yet available to the one or more partially constructed vehicle portions during the current build stage.

41. A computer-implemented method for verifying proper installation of equipment systems of a primary power busing network within a first modular equipment center (MEC), the method comprising, by operation of one or more non-transitory computer processors:

emulating, by operation of one or more non-transitory computer processors, data communications, over a data communications network, from one or more prerequisite equipment systems not yet installed in the one or more partially constructed vehicle portions, during the current build stage;

initiating one or more diagnostic tests, during the current build stage of the vehicle, using the emulated data communications of one or more prerequisite equipment systems, to determine whether one or more equipment systems of the primary power busing network within the MEC are correctly installed in the vehicle, without requiring the one or more prerequisite equipment sys-

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tems to be physically installed in the one or more partially constructed vehicle portions, comprising: routing a low voltage test power to a first plurality of contactors within the first MEC;

determining whether or not the low voltage test power is present at each of the first plurality of contactors of the first MEC; and

collecting contactor information from each of the first plurality of contactors across an internal MEC data network of the first MEC to a CNI module of the first MEC; and

upon determining that the one or more equipment systems are incorrectly installed, based on a failure of a first one of the one or more diagnostic tests, facilitating a correction of the failure of the first diagnostic test.

42. The computer-implemented method of claim 41 further comprising:

routing the low voltage test power to a second plurality of contactors within a second MEC;

determining whether or not the low voltage test power is present at each of the second plurality of contactors of the second MEC; and

collecting contactor information from each of the second plurality of contactors across an internal MEC data network of the second MEC to a CNI module of the second MEC.

43. The computer-implemented method of claim 42 further comprising providing the contactor information of the first plurality of contactors to the CNI module of the second MEC and configuring the second plurality of contactors of the second MEC based on the contactor information of the first plurality of contactors of the first MEC.

44. The computer-implemented method of claim 42 further comprising providing the contactor information of the second plurality of contactors to the CNI module of the first MEC and configuring the first plurality of contactors of the first MEC based on the contactor information of the second plurality of contactors of the second MEC.

45. The computer-implemented method of claim 41 further comprising emulating a second MEC having a second plurality of contactors to test collecting of contactor information of the second plurality of contactors at the CNI module of the first MEC.

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